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ERRATA

Vol. XXXVII, No. 7 (October–November, 1929), p. 697
Table III, Analysis II (F. F. Grout, analyst)

CORRECTED DATA

SiO_2	68.85
Al_2O_3	14.53
Fe_2O_3	1.29
FeO	2.64
CaO	.99
MgO	1.04
K_2O	5.69
Na_2O	3.02
H_2O+	.40
H_2O-	.10
TiO_2	.58
MnO	.13
P_2O_5	.21
BaO	.13
S	.01
Cl	.....
CO_2	.....
SO_3	.....
Cr_2O_3	trace
CuO	.....
ZrO_2	.04
SrO	none
LiO_2	.....
Rare earths	.02
Total	99.67

VOLUME XXXVII NUMBER 1

THE

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January-February 1929

MOUNT MONADNOCK, VERMONT—A SYENITE HILL

JOHN E. WOLFF

ABSTRACT

Mount Monadnock, Vermont (*circa* 3,200 feet), is the northernmost stock of alkali-syenite known in New England, and therefore the first in the southerly continuation of the eight similar "Monteregian Hills" of Canada—in all, nineteen such hills or mountains are marked on Figure 1, extending from Montreal, 215 miles, to Mount Agamenticus, Maine. Monadnock is a stock of quartz-nordmarkite, with an interior, older mass of essexite and with associated bostonite and camptonite dikes, intrusive into schists and quartzites of the upper Connecticut Valley, of probably lower Paleozoic age—the igneous rock much later, possibly Carboniferous. Descriptions of the minerals and rocks follow, including analyses of the hornblende, syenite, and essexite; an original topographic and geologic map; and two views of the mountain. Attention is called to the consanguinity shown by the minerals, and their combinations in the rocks, with those of the other hills.

INTRODUCTION

There occur in New England and the Province of Quebec a number of isolated hills or mountains, formed by massive intrusions of alkaline igneous rocks and associated dikes. In 1903,[1] F. D. Adams applied the name "Monteregian Hills" to the eight occurring in Canada (Mount Royal, above Montreal, the beginning of the chain); while in 1906, Pirrson and Washington suggested "Novanglian Petrographic Province" for those in New England.[2]

The New England list includes, from north to south (see Fig. 1 and numbers):

9. Mount Monadnock
10. Devil's Slide, Stark, New Hampshire, and others[3]

[1] References to other works (indicated by superior figures) are given at end of article.

11 and 11*a*. Burnt Meadow and Pleasant Mountains, south of Fryeburg, Maine (studied by E. S. C. Smith, but not yet described)

12. Tripyramid Mountain, New Hampshire[4]

13. Red Hill, New Hampshire[5]

14. Belknap Mountains, New Hampshire[2]

15. Granite Mountain, Cuttingsville, Vermont[6]

16. Mount Ascutney, Windsor, Vermont[7]

17. Mount Agamenticus, Maine[8]

18. Pawtuckaway Mountains, New Hampshire[9]

The eroded mass of alkaline rocks in Essex County, Massachusetts, in Quincy, Massachusetts, and in other areas in New England and beyond belong in the province but are beyond the narrow limits of this paper. Others may be found in unexplored areas of New England—in fact, J. H. Huntington[3] mentions several syenite mountains in New Hampshire on a line running S. 20° E. from Monadnock and contained in the ranges of mountains bounding the Connecticut Valley on the east: Sugar Loaf, 11 miles distant; Percy Peaks, 17 miles; and Devil's Slide and Mill Mountain, 21 miles. The rock from Devil's Slide is similar to the Monadnock syenite. Also nephelite and alkali syenites are found in a small area in Vermont on the east side of the Green Mountains and 78 miles southwest of Monadnock.[10]

The largest in ground area is Brome Mountain (see Fig. 1, No. 7), 30 square miles; next, the Belknap Mountains. (No. 14); the smallest, Mount Johnson (No. 8). The distance from Mount Royal (No. 1) to Agamenticus (No. 17) is about 215 miles. In Canada, six of the eight hills can be connected by a curved line (Mount, Royal to Shefford [No. 6]); while the other two would lie on a parallel line, suggesting possible lines of weakness or breaks in the earth's crust (Adams). For the New England Hills, several possible linear arrangements might be imagined, but only one seems definitely suggestive (Nos. 12–18, which lie on a straight line 58 miles long. The form of the intrusions varies from stocks of varying regularity, laccoliths, and one neck (Mount Johnson, No. 8). There are two dominant rocks for the whole chain; alkali-syenite of various types; and essexite, with satellitic dikes and sills. In several of the Canadian hills, nephelite, sodalite, aegirite, and alkali hornblendes are found; but in New England, the highly sodic minerals are found only at Red Hill and Cuttingsville (Nos. 13 and 15). The syenite

has often several facies in one stock; but in general, in any one area the number of distinct types is small, Ascutney having the greatest number.

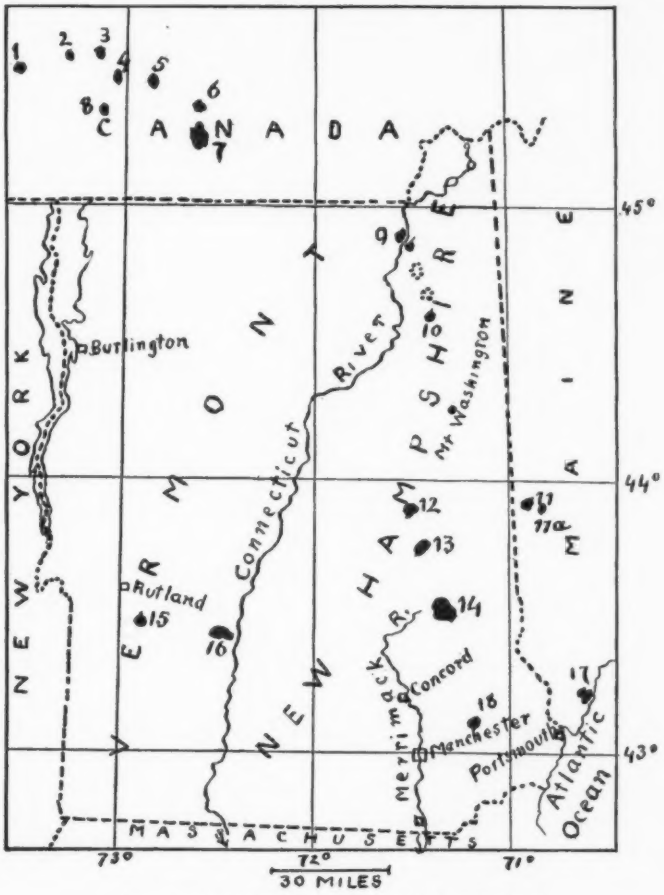

FIG. 1.—Syenite Hills of Canada and New England

MOUNT MONADNOCK, VERMONT

The mountain was named, by the early settlers, after its better-known namesake, Mount Monadnock (of physiographic fame) in

southwestern New Hampshire. It lies on the west bank of the Connecticut River, 30 miles below the river's head at the Fourth Connecticut Lake, at the Quebec boundary, but only 7 miles from the boundary on the Vermont side of the river; mainly in the township of Lemington, Vermont, and opposite Colebrook, New Hampshire, on the eastern bank. The river washes the steep east slope of the mountain and has probably cut its valley through the syenite, but covered the bedrock with alluvial filling, thus isolating (on the surface) the small area in Colebrook and Columbia, New Hampshire, from the main mass in Vermont (see map Fig. 2). The river at the base is 1,000 feet above tide; and the summit, about 3,200 feet. Three tributaries here join the river from the west: Willard Stream on the north has cut a deep gorge through the syenite; a smaller stream, Mountain Brook, heads in a great hollow in the center of the syenite; and a larger stream, Mill Brook, flows past the south end. On the New Hampshire side, Sim's Stream cuts a wide gorge through the syenite before entering the Connecticut.

The mountain has the typical form of these solid syenite masses, namely, a broad truncated cone, with oval base, many subordinate spurs, and in this case steep or precipitous slopes facing the river. A prominent rock bench (essexite) occurs on the southeast spur, 800 feet above the base (see Figs. 3 and 4, and map). The ground plan is oval, 3.6 miles north-south and 3 miles east-west; area 11 square miles, of which the igneous rocks occupy 4.9 miles plus 0.5 miles in New Hampshire, totaling 5.4 square miles. A rough estimate of the volume of igneous rock now exposed is 0.88 cubic mile—original volume 2.0 miles, eroded 57 per cent. There is no topographic map known to the writer, so the map (Fig. 2) was hastily prepared by plane table and sketching, the bridges over the river and some other well-marked points on the New Hampshire maps being used as starting-points; hence the author makes no claim to great accuracy. The geology also has not been noticed, except that Huntington[3] mentions the area in connection with the syenite of Colebrook and Columbia and that the whole area is accurately marked on the accompanying atlas of New Hampshire.

The country rock is a mica schist, passing in places, especially near the west and north contacts, into a micaceous quartzite. The

strike of the foliation (and stratification) is nearly north, and the dip east, 45°–15°; but at the extreme north end the quartzite is nearly

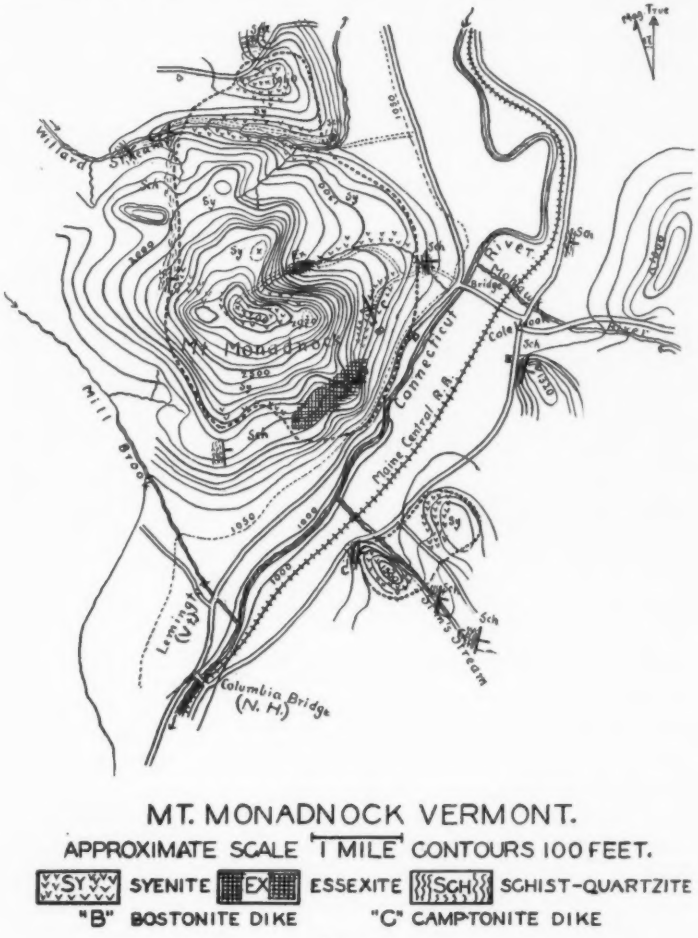

FIG. 2

horizontal, suggesting an anticlinal fold, and apophyses of the syenite penetrate the country rock in irregular sills parallel to the stra-

tification. At the only actual contact found (on the west face of the mountain), the line conforms roughly to the steep east-dipping stratification of the country rock; and in the gorges of Willard Stream and Mountain Brook, on both east and west sides the same attitude is indicated, although contacts are covered. In general, there is no marked disturbance of the inclosing schists near the intrusion, whose longer axis trends slightly west of the regional strike; so apparently the stock crosscuts the strike on the south, nearly conforms to dip on east and west sides, and again crosscuts at the

FIG. 3.—Mount Monadnock from hill 1500, 5 miles east. Colebrook, New Hampshire, in foreground; Connecticut River at east base; amphitheater and gorge of mountain brook right center; gorge Willard Stream extreme right; Essexite bench on skyline; two-thirds down south slope of mountain (left).

north. Xenoliths of schist are common in the syenite (stoping).

The small area in Colebrook and Columbia, New Hampshire, shows no actual contacts with the schist-quartzite; but the latter dips east on both sides of the syenite, suggesting the same combination of crosscutting and parallelism.

Distribution of the igneous rocks.—The main rock is an alkali-syenite, between quartz-nordmarkite and granite (69° per cent SiO_2, 10 per cent alkalies)—a massive, medium-grained gray rock, without pronounced jointing, composed of microperthite, albite, quartz, biotite, hornblende, and accessories, with frequent variations in the proportions of the last three, which the field work could not relate to position in the stock or the contacts. Exactly in the center of the syenite and 1,400 feet vertically below its highest point at the sum-

mit, an area of essexite is exposed in the bed of the Mountain Brook for a hundred yards or so, cut by tongues of syenite and camptonite dikes; but the exact extension, laterally and vertically, is concealed. A much larger exposed area of essexite occurs along the southeast side of the mountain, forming a prominent bench, which continues northeast for a mile, then cut off by syenite; the essexite forms cliffs extending down several hundred feet until covered by talus, the highest point on the bench 800 feet above the river, topped by syenite; this is at about the same topographic level as the smaller (ex-

FIG. 4.—Looking at south side of mountain from station 5½ miles W. of S. from summit. Valley of Mill Brook in center. The symmetrical shape of mountain again shown.

posed) area in the brook bed, the connecting line about parallel to the longer axis of the igneous area, so that they are probably parts of one interior mass of essexite surrounded and topped by syenite. This interior position of an older essexite mass is common in these syenite hills. The rock itself is dark, coarse-grained, composed of large prismoids of hornblende and augite, biotite, labradorite, and accessories.

The few dike rocks observed are described below.

PETROGRAPHY

THE MINERALS

Hornblende.—In the typical fresh syenite from the Norton mine, prisms of a lustrous, black hornblende, 3 mm. long at most, are

common, and were selected for chemical and optical analysis. The Leitz universal stage was used for the measurements of 2V, extinctions, birefrigence and pleochroism, using the methods and precautions prescribed by Berek,[11] supplemented by Berek compensator, Wright eyepiece, and eyepiece dichroscope, etc. Indices by immersion.

Indices:

$\gamma = 1.713$ $\gamma - \alpha = 0.020$
$\beta = 1.711$
$\alpha = 1.693$ $\dot{c}:\gamma = 20°–21°$

2V measured and reduced $43\frac{1}{2}°$ (−). Computed from indices $44\frac{1}{2}$

Pleochroism:

γ = deep grass green
β = deep olive green
α = light yellow

Analyses of similar amphiboles and tabulation of their optical properties are added for comparison—Tables I and II, the former including some from outside regions; the latter, with one exception (Idaho), from the alkaline rocks of the Monteregian and New England provinces. It is seen that the complete optical properties are rarely given (at least in publications at hand), and apparently in no case was the Universal stage used for accurate orientation of the side pinacoid ($\gamma:\dot{c}$); but even then the chemical and optical similarity is evident, and illustrates the peculiar position of amphibole as a test for consanguinity.

In other parts of the Monadnock syenite and New Hampshire extension, the optical properties are in general similar ($\gamma:\dot{c} = 19°–22°$), pleochroism tending to more greenish-brown tints, only that from the Devil's Slide has the same deep green yellow, but here $\gamma:\dot{c}$ is 12° and $2V = 70°$, and in general 2V is larger than in the type specimen (58°–70°), indicating a change in the composition, and therefore in the indices; but how much of this may be due to conditions in the magma or to paramorphism due to weathering is uncertain. The essexite amphibole has $\gamma:\dot{c} = 12°$; $2V = 70°$ (−); $\gamma - \alpha = 0.023$; γ and β = deep chestnut brown, α = lighter, yellowish brown.

The Cuttingsville, Vermont, hill, 120 miles southwest (well described by J. W. Eggleston[6] has nordmarkite and essexite facies similar to Monadnock and corresponding amphibole (see Tables I and II). From material kindly furnished by Dr. Eggleston, the opti-

TABLE I

ANALYSES OF AMPHIBOLES*

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
SiO_2	38.72	38.50	38.04	35.65	45.4	34.18	38.63	38.41	35.42	37.49	36.86	37.40
TiO_2	5.03	tr	1.06	7.09	4.0	1.52	5.03	1.26	1.34	0.86	1.04	3.20
Al_2O_3	10.94	10.88	13.50	11.94	.....	11.52	11.97	16.39	8.89	10.81	12.10	12.34
Fe_2O_3	4.33	6.70	6.21	5.92	16.8	12.62	3.90	3.75	9.73	7.52	7.41	4.16
FeO	26.03	27.28	15.85	12.04	22.0	21.98	11.52	21.75	24.48	25.14	23.35	25.84
MnO	0.88	tr	1.21	0.10	.....	.....	0.73	0.15	1.17	0.95	0.77	1.24
CaO	8.55	11.30	12.42	11.21	4.2	9.87	12.81	10.52	6.93	9.77	10.59	9.72
MgO	2.19	1.40	7.26	11.01	0.6	1.35	10.20	2.54	0.17	1.34	1.90	2.20
K_2O	1.25	1.66	1.68	0.99	.....	.....	1.49	1.95	3.23	1.91	1.20	1.36
Na_2O	1.39	1.22	3.21	2.33	6.7	3.29	3.14	2.95	5.13	2.06	3.20	1.80
H_2O+	1.22	1.27	0.48	.....	.....	.....	0.33	0.24	3.15	2.01	0.60	0.00
H_2O-	.....	.....	.....	NiO 0.04 SrO 0.01	.....	Rest 3.26	.....	.....	.....	.....	0.70	0.69
	100.53	100.16	100.92	99.59	99.7	99.59	99.76	99.96	99.64	99.86	99.72	99.86
Sp. Gr	3.422	.....	3.518	.....	.....	.....	.....	.....	.....	.....	.....	3.375

* I, Monadnock, Vt.; II, iron amphibole from Idaho, E. V. Shannon;[13] III, from syenite, Cuttingsville, Vt., C. D. Test;[6] IV, from essexite of Mount Royal, J. B. Robertson;[14] V, riebeckite in paisanite, Red Hill, N.H., Pirrson and Washington;[3] VI, hastingsite, Harrington;[15] VII, Mount Johnson, Quebec, N. Evans;[1] VIII, barkevitic hornblende, sodalite-syenite, Square Butte, L. V. Pirrson;[16] IX, alkali iron amphibole from umptekite, F. E. Wright;[17] X, hastingsite, (umptekite), Almunge, Sweden;[18] XI, hudsonite, Cornwall, N.Y., Nelson and Daniells;[19] XII, ferrohastingsite from nordmarkite, Jackson, N.H., W. H. Herdsman.[19]

TABLE II

Optical Characters of Amphiboles

	Indices			$\gamma-\alpha$	2V	Pleochroism			$\gamma:c$	Optical Sign
	γ	β	α			γ	β	α		
Mount Monadnock, syenite	1.713	1.711	1.693	0.020	43½°	deep grass green	olive green	light yellow	20°–21°	$(-)\gamma>\beta>\alpha$ 2V from indices 44½°
Mount Monadnock, essexite				0.023	70°	deep chestnut-brown	deep chestnut-brown	light yellow	12°	$(-)\gamma=\beta>\alpha$
Cuttingsville, Vt., syenite	1.712	1.710	1.693	0.019	63°	chestnut-brown	chestnut-brown	light yellow-brown	13°–14°	$(-)\beta>\gamma>\alpha$. Outside green. 2V from indices 65½°
Cuttingsville, Vt., essexite	1.700	1.694	1.683	0.017	72°	chestnut-brown	chestnut-brown	light yellow-brown	12°	$(-)$ 2V from indices 73°
Monteregian Hills:										
Mount Royal, essexite[14, 15]	1.705	1.692	1.676	0.029	76°				16°	
Mount Johnson, essexite[15, 16]	1.703	1.692	1.670	0.033	80°				15°	
St. Bruno, essexite[15]									19½°	
St. Hilaire, essexite[15]							γ and β dark reddish brown, with variation in relative intensities		14°	
Rougemont, essexite[15]								light yellowish brown	17°–28°	$(X)\beta>\gamma>\alpha(-)$
Brome, essexite[15]									20°	
Shefford, essexite[24]									27°	
Shefford, nordmarkite[24]						deep green	yellow-green	straw color	26°	
Yamaska, akerite[25]						dark brown	dark brown	light yellow-brown	14°	
St. Hilaire, nephelite-syenite[22]						yellow-brown	deep brown-green	yellow-brown		
Tripyramid Mountain, nordmarkite[4]	main crystal	crystal ends		0.018 low		yellow-brown	yellow-brown	pale yellow	16°–18°	$\beta>\gamma>\alpha$
Belknap Mountains, syenite[3]						strong blue-green		pale greenish gray	25°	$\gamma>\beta>\alpha$
Belknap Mountains, camptonite[3]						olive to deep green	olive-brown	pale brown	18°	
Belknap Mountains, essexite[3]				0.020		deep brown	deep brown	pale yellow	18°–20°	$\gamma>\beta>\alpha$
Red Hill, foyaite[3]				low		umber-brown	olive-brown	pale brown-yellow	18°	$\gamma>\beta>\alpha$. Trans. to green var.
Ascutney, nordmarkite[7]					70°	deep olive-brown to olive-green	deep olive	light yellowish brown	30° or more	
Beverly, Mass., umptekite[17]	$\gamma-\beta=.0013$ $\beta-\alpha=.0209$			0.0222	36°	gray olive-green	green-brown to olive	light yellow-brown	16°	
Idaho, crystaline limestone[12, 18]	1.713	1.710	1.693	0.010	small	blue-green	olive-green	greenish yellow	20½°	
Jackson, N.H., nordmarkite[12]	1.722	1.719	1.698	0.024	47°	smoky blue-green	brownish green	greenish brown	17°	$(-)\gamma>\beta>\alpha$. 2V from indices 45° app.
Campton Falls, N.H., camptonite[12]	1.705	1.695	1.680	0.025	large	deep green	olive-green	yellow	20°	$(-)$
						deep brown	brown	light yellowish brown	11°	$(-)$. 2V from indices 78°

cal constants have been amplified by the newer methods. In the syenite, the crystals have a deep-green exterior, transitional to a brown-yellow interior; in the former 2V is 42°, in the latter 61°, with indices close to those of the green crystals of Monadnock; in the essexite the indices are lower and $2V = 72°$, with pure brown-yellow pleochroism. Since these rocks are fresh, it is evident that, with both rocks, in the earlier stages the crystals represented the pure brown variety; but in the more acid syenite, the composition gradually changed to form the green.

Augite.—Rare in the syenite but abundant in the essexite. In the Devil's Slide syenite, a deep-emerald-green diopsidic augite is associated with the amphibole ($2V = 65\frac{1}{2}° +$) $\gamma : \dot{c} = 45°$. In the essexite, the larger augites have a faint pinkish color (titanium?), 2V from 52° to 63° (+), $\gamma : \dot{c} = 40°–45°$; the Cuttingsville essexite has the same.

Biotite.—The biotite of the rocks has a deep-brown-yellow pleochroism, reddish in the syenite, 3° extinction to cleavage, and a large axial angle, 2E from 28° to 18° in different specimens, average 24° (+or−3°). Cuttingsville is similar.

Titanite.—In the essexite, gives $2E = 58°$ (white light).

Feldspars.—These are described with the rocks.

THE ROCKS

Syenite.—The freshest (quarried) syenite from the Norton mine was selected for detailed study. It lies 500 feet above the east base of the mountain, and well in from the contact. It is a medium-grained, light-greenish-gray rock, with small black prisms of hornblende prominent. *Section:* Aside from the hornblende and scant biotite plates, the bulk of the rock is composed of quartz and feldspar. The latter is a coarse microperthite, the potash element usually a sodium-orthoclase, but sometimes microcline, both giving 6°–7° on M; the albite is an albite-oligoclase ($14\frac{1}{2}°$ perpendicular to M, An 14), the proportions of the two elements being variable. A subporphyritic texture is caused by larger crystals in a groundmass of microperthite crystals, separate albite grains and quartz. Allanite in large, rounded crystals is common; zircon, abundant, sometimes associated with areas of fluorite; a little magnetite and apatite. Occasional clumps of altered allanite, inclosing secondary actinolite prisms, and

surrounded by a rim of apatite, magnetite, zircon, biotite, hornblende, and augite represent segregations of the earlier formed minerals. The analysis, norm, and mode (Rosival) are given in Table III, with analyses of nordmarkites from Cuttingsville and Ascutney (further analyses from the province are given by Eggleston[6]; they show a close relationship, but this rock has the highest silica and might be termed a quartz-nordmarkite, transitional to granite.

The syenite from other parts of the stock and in New Hampshire show variations in the proportions of the minerals and have occasional augite and titanite. Biotite may be the sole mafic mineral, and hornblende and biotite may be equal or both may disappear; but no reason was found for these changes.

Essexite.—This is older than the syenite, as seen in a contact in the Mountain Brook, where it is cut by tongues of the former, with an intervening mixed zone, indicating near contemporaneity of the two rocks. It is a dark, medium-coarse, granular rock, with equal amounts of feldspar, biotite, hornblende, and augite, and visible titanite. The labradorite lathes produce an ophitic texture. *Section:* Large prisms of deep brown to yellowish hornblende, often green by paramorphism, pale-green augite with reddish core, biotite plates, and stout lathes of labradorite (Ab^1 An^1), with accessory titanite, apatite, titaniferous magnetite and a rare grain of quartz. Its analysis (Table III) norm and mode (Rosival) are similar to many of this type (cf. No. 4, Cuttingsville, and others tabulated by Eggleston[6]).

Dikes.—A few were found in both areas, doubtless more are concealed by the forest cover.

Quartz-Bostonite.—A dense, yellowish-gray rock cuts the syenite at the Norton mine as a dike 11 feet wide. Composed of thin plates of a blotchy albite-orthoclase-mixed feldspar and a little interstitial quartz, with abundant areas of calcite, pyrite, muscovite, etc., as decomposition products, the whole rock being too decomposed for accurate study.

Aplites.—These vary in width from 11 feet down to small irregular stringers, and cut syenite, essexite, and schists. They are fine-grained white rocks, with slight content of dark minerals at most, granular or porphyritic, and represent an acid phase of the

TABLE III

ANALYSES OF ROCKS*

	1	2	3	4	5
SiO_2	69.43	46.09	67.30	46.47	65.43
Al_2O_3	15.67	17.29	17.44	16.86	16.11
Fe_2O_3	0.36	1.63	1.56	3.21	1.15
FeO	2.50	7.26	1.76	7.72	2.85
MgO	0.12	8.04	0.14	5.16	0.40
CaO	1.13	7.89	1.00	9.45	1.49
Na_2O	5.11	3.68	7.08	4.20	5.00
K_2O	4.97	1.92	4.78	1.35	5.97
H_2O+	0.42	0.77	0.05	0.45	0.39
H_2O-	0.01	0.12	0.05	0.04	0.19
TiO_2	0.18	4.49	0.17	2.86	0.50
ZrO_2	0.06	n.d.	0.08	.....	0.11
P_2O_5	0.06	0.90	0.04	1.15	0.13
S	0.07	0.10	.....	.....	0.036
MnO	0.06	0.16	0.16	0.23	0.23
BaO	abs	0.09	.....	tr	0.03
SrO	n.d.	tr	.....	0.04	tr
	100.11	100.43	101.61	.....	.....
FeS_2	.....	.....	.....	0.21	0.07
Fe_7S_8	.....	.....	.....	0.08	.....
Cr_2O_3	.....	.....	.....	abs	.....
Li_2O	.....	.....	.....	abs	tr
F	.....	.....	.....	0.10	0.08
SO_3	.....	.....	.....	abs	abs
Cl	.....	.....	.....	0.06	0.05
CO_2	.....	.....	.....	tr	.....
				99.64	100.18
Sp. Gr	.....	.....	.....	2.919	2.659

1a		1b		2a		2b	
Q	16.68	Qu.	16.4	Or	11.12	Lab	35.8
C	0.20	Microp	62.0	ab	20.44	Oligo	1.4
Z	0.10	Alb	15.6	an	25.02	Ortho	0.2
or	29.47	Ho	4.2	ne	5.96	Qu	0.2
ab	42.97	Bi	0.1	di	10.92	Bi	16.2
an	4.73	Zir	0.2	ol	13.22	Ho	16.9
hy	4.39	Allan	0.5	mt	2.32	Aug	16.2
mt	0.70	Magn	0.3	il	8.51	Mag	9.3
il	0.50	Dec.	0.4	ap	2.02	Tit	0.2
ap	0.30			pr	0.24	Apat	2.7
pr	0.10	Allan	99.7			Pyr	0.9
	100.04				99.77		100.9

* 1, Quartz-nordmarkite, Mount Monadnock, J. E. Wolff. *1a*, Norm of same; Toscanose to Lassenose: I 4, (1)2, 3(4)—). *1b*, Mode (Rosival).
2, Essexite, Mount Monadnock, J. E. Wolff. *2a*, Norm; Camptonose; (II) III, 5, 3, 4. *2b*, Mode (Rosival).
3, Nordmarkite, Cuttingsville, Vt., C. D. Test (Eggleston).[6]
4, Essexite, Cuttingsville, H. E. Merwin (Eggleston).[6]
5, Nordmarkite, Ascutney, Vt., W. F. Hillebrand (Daly).[7]

syenite, with orthoclase-microperthite and quartz as essentials, and zircon, titanite, allanite, apatite, and pyrite as accessories; in one case, abundant diopside, with some hornblende and biotite.

Camptonitic dikes.—These are the latest igneous rocks, cutting syenite, essexite, and bostonite, varying from 10 to 3 feet in width. The black, fine-grained rocks contain small phenocrysts of the dark minerals. In some the phenocrysts are biotite and barkevitic hornblende ($\gamma : \dot{c} = 16°$, $2V = 70°$); in others a diopsidic augite ($\gamma : \dot{c} = 44°$, $2V = 57°$). The groundmass has a plagioclase varying from labradorite (An_{50}) to basic andesine or oligoclase; the hornblende in acicular prisms may be associated with augite or biotite. A little quartz filling is common; also titanite, magnetite, apatite. In general, the rocks are similar to the typical camptonites of Livermore Falls, New Hampshire, but, like them, lack the large lustrous phenocrysts found in many camptonites.

SEDIMENTS

The country rock adjacent to the syenite is a quartz-rich mica-schist or micaceous quartzite, in which quartz grains predominate, with some feldspar, both orthoclase and oligoclase. Parallel plates of biotite are abundant, muscovite, scant or wanting; and accessory pyrite, magnetite, apatite, and titanite present. Larger, rounded grains of zircon and of feldspar, inclosed in an aggregate quartz cement, are considered clastic; otherwise a typical schist.

Contacts.—At or near the contact with the syenite, an intimate mixing of the two rocks is evident, with mineralogical changes or accessions on the schist side, especially an abundance of biotite and some grains of microperthite. The syenite has finer grain and porphyritic texture and enrichment in biotite, similar optically to that in the schist. Exceptionally peculiar mineral combinations are found in the schist, which may be mainly attributed to the igneous rock, although earlier regional metamorphism may contribute. In one case the banded quartzite has little biotite or muscovite, but large crystals or aggregates of a pale-greenish-brown amphibole ($\gamma : \dot{c} = 17°–20°$), intergrown with droplets of quartz and with a granular labradorite, also occurring in bands—all forming a cement for the larger quartz grains of the rock, with other bands of garnet, and the clastic zircons and other accessories of the normal schist. Again

the contact rock, finely banded, is composed of oval quartz grains with anhedral grains of diopside, basic oligoclase, and titanite as a cement. At another place the banded contact rock is quartz-free, and composed of prismoids of hornblende (identical with that of the syenite), biotite plates, anhedral crystals of orthoclase and oligoclase, titanite and magnetite.

CONCLUSION

Mount Monadnock adds one more to the series of these peculiar hills, nineteen of which are located but not all described. Aside from the geological features as here outlined, and the chemical relations of its two principal rocks to those of the others, the further evidence of consanguinity given by detailed study of the amphibole common in all the hills has seemed worth the space devoted to it. The larger problems of the consanguineous rocks here and in the great area extending from Maine (Litchfield), Massachusetts, the Connecticut Triassic (Monchiquite), New Jersey (Beemerville); Brookville (Triassic), central New York and intervening territory (camptonites, bostonites, etc., here and there), and in Canada; the age of the intrusions; factors affecting their distribution; depth of the original cover; physiographic study of these "monadnocks"; etc., are not discussed here, the writer believing this should await further discovery and study.

NOTE: As this article was ready for the press, an interesting and valuable paper on the Hastingsite group, by M. P. Billings, was received,[12] in which new optical and chemical data are given and subdivisions of the group based on the ratios of FeO and MgO are proposed. Figures bearing directly on this paper have been added to the tables. The amphibole of the Monadnock nordmarkite would belong to the subdivision named "ferrohastingsite."

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THE KLINTAR OF THE UPPER WABASH VALLEY IN NORTHERN INDIANA

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ABSTRACT

The Wabash sluiceway between Huntington and Peru is characterized by numerous moundlike rocky hills which are composed of the unreduced portions of Niagaran coral and stromatoporoid reefs. Hills of a similar character on the Island of Gotland are called "Klintar," and that name is adopted in this paper. The upstream end of the northern Indiana klintar is always abrupt, but the downstream portion is frequently concealed by long low tails of inter-reef bed rock or of glacial drift. Some of the klintar were in existence in preglacial times, while others were formed during the excavation of the Wabash sluiceway by the escaping glacial-flood waters. Attention is called to klintar elsewhere in this country and also in Europe.

INTRODUCTION

The upper part of the Wabash River Valley is chiefly an old glacial sluiceway, owing its origin to the erosional work of the escaping glacial-flood waters and to the outlet waters of glacial Lake Maumee in late Pleistocene time. In this sluiceway occur numerous moundlike rocky hills which have recently been shown to comprise the unreduced portions of Niagaran coral and stromatoporoid reefs[2].

These reefs are generally mound-shaped masses of calcareous material consisting of a central, massive, unstratified core, against which lean well-stratified beds inclined at high angles. At the peripheral extremity of the reef these inclined reef-flank strata flatten out and grade into or interfinger with the normal inter-reef formations. Because of its greater resistance, this reef mass frequently stands up as an erosion remnant or rocky hill, from around which the less resistant inclosing materials have been partially or entirely removed.

Similar features on the Island of Gotland in the Baltic Sea are called "klintar."[3] The term has not, however, come into general use in this country.

[1] Contribution from the Waterman Foundation, No. 34. The writer wishes to thank Professor Clyde A. Malott for his kind criticism and many helpful suggestions.

[2] E. R. Cumings and R. R. Shrock, "The Silurian Coral Reefs of Northern Indiana and Their Associated Strata," *Ind. Acad. Sci., Proc. for 1926* (1927), pp. 77–85.

[3] Carl Wiman, "Über Silurische Korallenriffe in Gotland," *Bull. Geol. Inst. Upsala*, Vol. III (1896–97), pp. 311–26; A. W. Grabau, Principles of Stratigraphy (1924), p.

It is the purpose of this paper formally to introduce the terms "klint" and "klintar" (plural) into the topographic nomenclature of this country with a very definite but restricted meaning, and to indicate by means of description, photographs, and sketches the specific characteristics of these very interesting topographic features. The writer has taken the liberty of calling attention to klintar elsewhere in America and in Europe in order to show how they compare with the ones found in northern Indiana.

DEFINITION AND DESCRIPTION

The term "klint" (plural, "klintar") may be applied to *any erosion remnant composed essentially of the unreduced portion of an ancient organic reef.*

The term "reef" is here used in a general sense to include any lenticular, cylindrical, mound-shaped, or irregularly shaped accumulation of organic remains, or of material directly derived therefrom. The reef-building organisms may be corals, stromatoporoids, bryozoans, brachiopods, crinoids, pelecypods, sponges, trilobites, cephalopods, algae, etc.

Because of the usual greater resistance of such structures as compared with the less resistant inclosing rock, they may give rise to a distinct topographic form, when through differential denudation the inclosing strata are removed.

The topographic form may be a dome-shaped or moundlike rocky hill, a cylindrical or stacklike rocky remnant, a promontory or headland, an island, a rocky ridge which may be oblong or elongated, conical or mesa- or buttelike, rectangular or irregular, or a combination of any of the foregoing. The form will primarily be dependent on the original contour of the reef mass. In some cases

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420; W. H. Twenhofel, *Expedition to the Baltic Provinces of Russia and Scandinavia, 1914* (1916), Part III, "An Interpretation of the Silurian Section of Gotland," *Bull. Mus. Comp. Zoöl.*, Harvard College, Vol. LVI, No. 4 (Geol. Ser., Vol. X, "Shaler Mem. Ser.," No. 3) (1916), pp. 347–48; *Treatise on Sedimentation* (1926), p. 226.

Dr. E. R. Cumings and the writer have used the terms "*klint*" and "*klintar*" (plural) in their field notes and teaching for some time, and also in a joint paper which will be published in the *Bulletin of the Geological Society of America* for 1928. The writer has briefly described these features in a paper which will be published in the *Proceedings of the Indiana Academy of Science* for 1927.

while the reef mass may be directly responsible for the feature, yet the contour of the form may be largely determined by the degree to which the inclosing materials have been removed, or the form may be only a remnant of the reef, left as an upstanding feature, sometimes of rather spectacular character. The size of the klint may vary from less than one hundred feet to thousands of feet in width, and from a few feet to several hundred feet in height. The klintar of northern Indiana do not exceed 80 feet in height and 3,000 feet in greatest width.

HISTORY OF THE NORTHERN INDIANA KLINTAR

In Niagaran time a great series of reef mounds, possibly a great barrier reef, extended from New York across northern Ohio and Indiana and northeastern Illinois into eastern Wisconsin. As the corals, stromatoporoids, and other reef-building organisms built up the more or less irregular reef mounds, the calcareous and siliceous muds, derived partly from the destruction of the reefs and partly from the adjacent land mass, formed the stratified limestones and shales of the inter-reef expanses. Deposition subsequent to the reef-building period buried both the reefs and their inclosing strata to an unknown depth. It is quite likely that they were covered with Devonian formations, and perhaps even with Mississippian and Pennsylvanian strata.

At the close of the Paleozoic, both the reefs and their inclosing materials and the superincumbent strata were elevated above sea-level and subjected to a long period of denudation which continued without interruption until Pleistocene time. During this long period of denudation the overlying strata were removed over a large area, and the reef-bearing formations themselves were revealed and partly eroded away. The resistant reef mounds withstood denudation much better than the inclosing strata, so that at the beginning of the Pleistocene many of these ancient reef masses stood up as isolated rocky hills, denuded partly or entirely of their inclosing strata.

As the Pleistocene glacier transgressed this old erosion surface, the heavy deposition of drift buried all of the bed-rock features. Then, as the glacier retreated, the flood waters escaping through the Wabash sluiceway rapidly cut down through the drift mantle

resurrecting and reshaping some of the preglacial klintar and bringing others into existence for the first time. At the same time the alluvial terraces, "scablands," and other unreduced masses of bed rock with which the klintar are associated came into existence (see Fig. 2). Tongues of drift or bed rock frequently extend downstream from the reef mass. The upstream side of the klint is usually abrupt and often is the only part that may be directly observed.

DESCRIPTION OF THE NORTHERN INDIANA KLINTAR

The klintar of northern Indiana are bed-rock hills, in shape not unlike an inverted bowl; or rocky ridges, the upstream portion consisting of a partially destroyed reef mass standing up as a bulwark and protecting the low, narrow tongues of unremoved inter-reef bed rock that extend downstream from the reef mass; or finally, low mounds of rock without any particular shape or contour, yet unreduced because of their superior resistance. Frequently much of the klint, and in some cases almost all of it, may be concealed by a variable thickness of drift, so that perfectly denuded klintar are rarely found. Tongues of drift, long protected from erosion, in many cases extend downstream from the klintar as low ridges.

Peru.—The Wabash trough or valley way is characterized by numerous linear upland masses which rise above the higher floodplain level of the valley floor. At Peru one of these upland tracts with a rather sharp apex extends west from the northern part of the city, splitting the valley into two troughs. Outcrops of reef rock at the top of the hill on North Broadway Street indicate the character of the upstream apex of the mid-valley ridge. Well logs show a considerable thickness of drift short distances away from the outcrop, and the flood plain of the Wabash River lies many feet below. Although much drift obscures the reef rock, it appears that the mid-valley ridge probably owes its existence to the presence of the klint which acted as a protecting bulwark against the glacial waters that carved out the troughlike valley of the upper Wabash.

One and one-fourth miles northwest of Peru, two small, low klintar, the larger about 100 feet in diameter, rise 20 feet above the cobble-strewn floor of the valley braid that separates the upland mass described above from the north bluff of the Wabash sluiceway. Both klintar have steep upstream sides. The smaller one is an iso-

lated rocky mound, but the larger one has its downstream side concealed by a low ridge of drift.

Mill Creek.—In the Wabash sluiceway in western Wabash County at the mouth of Mill Creek, which enters the river from the south about 4 miles west of the city of Wabash, occurs a large rock hill standing over 60 feet above the flood-plain floor. This abruptly rising hill is somewhat more than 300 feet across and is composed of reef rock which is conspicuously exposed in its blufflike, cavern-

FIG. 1.—View of a klint 1 mile east of Wabash, Indiana. This hill rises 45 feet above the valley flat. The view is looking north. Note the tongue of glacial drift extending downstream (to the left).

scarred upstream side. It is truly a klint which has been carved out and shaped by the waters which cut out the Wabash sluiceway. The downstream side of this klint is concealed by inter-reef limestone and glacial drift, which tail downstream from the craggy klint.

Wabash.—One mile east of Wabash, between the Wabash Railroad and State Road 24, lies a mid-valley, elongated ridge of drift, at the upstream end of which occurs a large, round, flat-topped rocky hill, not unlike an inverted shallow bowl, even to the steeply sloping sides. Reef rock is exposed on the south and east sides and on the top of the klint. The klint is over 350 feet across and rises at least 40 feet above the surrounding valley floor, forming a striking topographic feature (see Fig. 1).

Lagro and vicinity.—In the west edge of Lagro, State Road 24 passes between two klintar. The east and south slopes of the south klint are exposed and are very abrupt, the latter slope being over 45° and conforming with the dip of the steeply inclined reef-flank strata. This klint forms the upstream end of the mid-valley upland remnant (shown on the block diagram, Fig. 2), which extends downstream from Lagro. The smaller klint on the north side of the road, while almost completely mantled with drift, is more or less isolated, standing apart above the floor of the valley.

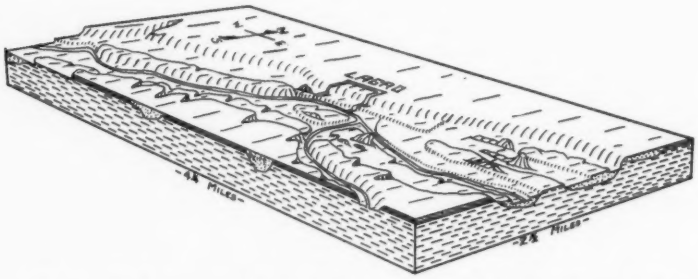

FIG. 2.—Block diagram of the Wabash sluiceway in the vicinity of Lagro, Indiana, showing the relations of the klintar to the alluvial and bed-rock terraces, rock remnants, and mid-valley ridges. The mid-valley ridge just west of Lagro has a klint at its upstream end. Both the Wabash and Salamonie rivers are entrenched 75 to 90 feet below the upland till plain.

One mile east of Lagro between the Wabash Railroad and the Wabash River are three elongated klintar whose longer axes parallel the direction of the river. The form and topographic relations of these klintar are shown on the accompanying block diagram (Fig. 2) and on the topographic sketch (Fig. 3). Klint No. 1, which bears a striking resemblance to a huge inverted bowl, is about 350 feet in diameter and rises domelike over 45 feet above the valley floor. The north, east, and south slopes are dip slopes of about 45°. The west slope is mantled with a tongue of drift which extends downstream from the klint for over a thousand feet.

Klint No. 2 is very impressive when viewed from the upstream end. It rises abruptly above the valley floor to the height of more than 60 feet (Fig. 4). This ragged, upstanding reef mass formed a

great stony bulwark protecting a low, narrow tongue of inter-reef shale which extends downstream for a distance of more than 1,200 feet. This klint was probably brought into existence during the excavation of the Wabash sluiceway, as indicated by the tongue of inter-reef bed rock still unremoved.

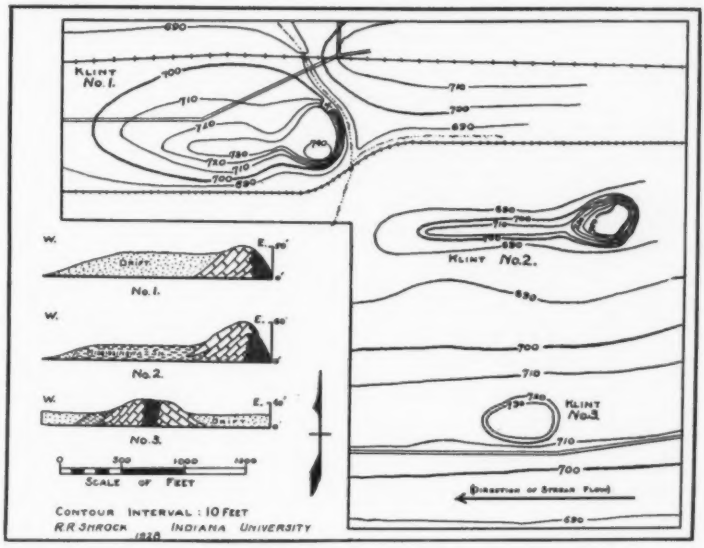

FIG. 3.—Topographic sketch of three klintar 1 mile east of Lagro, Indiana. These klintar are also shown on the block diagram (Fig. 2). The cross-sections show their approximate structure.

Klint No. 3 is a flat-topped rocky hill almost completely surrounded by drift. It is probable that to the west there is a remnant of shale, for numerous weathered pieces were noticed lying about. This klint is about 350 feet across and rises from 20 to 25 feet above the alluvial terrace which surrounds it. The exact structure of this klint is problematical, hence the cross-section (Fig. 3) is hypothetical.

"Hanging Rock," located 1 mile southeast of Lagro on the south side of the Wabash River, is a fine example of a klint which consists of a remnant of a reef. This rocky remnant towers with ragged

craggy sides over 75 feet above the river which sweeps its base. It is composed of irregular, slanting wedges of reef-flank rock. The core lay to the north of the present remnant. The accompanying photograph (Fig. 5) shows the spectacular character of this well-known feature. Twice buried beneath superincumbent formations, and as many times resurrected, this battle-scarred veteran, almost com-

FIG. 4.—View of Klint No. 2, one mile east of Lagro, Indiana, looking north. This klint is nearly 60 feet high. The dip slope on the side toward the observer is nearly 45 degrees. A low, narrow ridge of inter-reef shale extends downstream (to the left) from the klint for over 1,200 feet.

pletely denuded of its inclosing materials, still mocks the efforts of the elements.

Just across the road from Hanging Rock, and also a short distance west, are two smaller klintar which form low, rounded hills. These are probably isolated remnants of the same reef, which has been nearly destroyed by the same glacial waters that cut out the great valley trough of the Wabash. Several small klintar occur between the Wabash and Salamonie rivers 2½ miles southeast of Lagro (see Fig. 6).

Lagro to Huntington.—A number of small klintar were noticed between Lagro and Huntington along State Road 24. While these

klintar are less spectacular than the ones described above, they nevertheless exhibit the klint form, and meager outcrops of reef rock specifically class them with the peculiar topographic forms with which this paper deals. These low hills and mounds are made conspicuous by the presence of farm buildings and clumps of trees on them.

FIG. 5.—View of Hanging Rock, one mile southeast of Lagro, Indiana, looking west. This rocky klint rises over 75 feet above the Wabash River which sweeps its base.

OTHER KLINTAR IN NORTH AMERICA

United States.—Alden mentions a number of features in the vicinity of Chicago which are apparently klintar. He describes Stony Island (which has long been considered a coral reef by the Chamberlins and others at the University of Chicago) as "a somewhat elliptical ridge, 1¼ miles long and one-half mile wide, with the long axis in an east-west direction. It has a relief of 20 to 25 feet above the surrounding marshy plain."[1]

T. C. Chamberlin[2] was the first to show that the domelike mounds in the Racine limestone of Wisconsin are ancient coral reefs. He mentions moundlike hills near Cedarburg, Granville, and Milwaukee which are klintar. Alden[3] gives some further details of the klintar near Milwaukee and Wauwatosa. These features reach 50 feet in height and are several hundred feet across.[4]

[1] W. C. Alden, "Description of the Chicago District," *U.S. Geol. Surv., Geol. Atlas, Chicago folio* (No. 81), (1902), p. 3.

[2] T. C. Chamberlin, "Geology of Eastern Wisconsin," *Geol. Wis.*, Vol. II (1877), pp. 363–65.

[3] W. C. Alden, "Description of the Milwaukee Quadrangle, Wis.," *U.S. Geol. Surv., Geol. Atlas, Milwaukee folio* (No. 140), (1906), p. 2.

[4] A. W. Grabau, "Paleozoic Coral Reefs," *Bull. Geol. Soc. Amer.*, Vol. XIV (1903), pp. 341–42; *Principles of Stratigraphy* (1924), pp. 418–19.

Grabau[1] mentions coral reefs of Hamilton age (Middle Devonian) at Alpena, Michigan, whose "occurrence is marked in the topography by low mounds or swellings which rise above the general level of the country. . . . ."[2]

Canada.—Bell describes "great, spongey and cavernous" limestone masses along the Attawapiskat River in the Province of Keewatin, which are reefs of stromatoporoids and brachiopods. These masses frequently stand up 40 feet in relief when the softer inclosing

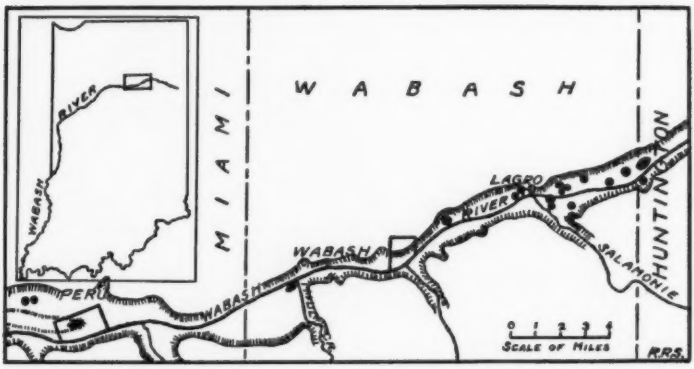

FIG. 6.—Sketch map showing the location of the known klintar of northern Indiana, and their relations to the Wabash sluiceway. The klintar are indicated by small dots.

materials have been removed. Some form islands in the river. They are locally called "wigwams" by the Indians.[3]

Williams mentions reef structures in Lake Huron which may be considered as klintar. He states that reefs occur on "Middle or 'Plucky Island' and on Lucas and Yeo islands. In fact it is to massive reef structure that these islands owe their preservation."[4]

KLINTAR OF EUROPE

The Island of Gotland in the Baltic Sea is one of the classic localities of the world for the study of ancient coral and stromato-

[1] A. W. Grabau, *Principles of Stratigraphy* (1924), p. 417.

[2] *Ibid.*

[3] Robert Bell, "Reef Structures on Attawapiskat River," *Geol. and Nat. Hist. Surv. of Canada*, Ann. Report, Vol. II (1887), pp. 27G, 28G.

[4] M. Y. Williams, "The Silurian Geology and Faunas of Ontario Peninsula, and Manitoulin and Adjacent Islands," *Can. Geol. Surv., Dept. Mines*, Mem. 111, No. 91, Geol. Ser. (1919), p. 74.

poroid reefs, and one might add for the study of klintar, for this is the type locality for the features discussed in this paper.

Murchison[1] long ago pointed out the reef character of the rocks of Lanna along the coast of Gotland, where they form conspicuous stacks, and Wiman later showed that certain types of klintar on the northwest coast of the island are reef structures.[2] Because of their superior resistance to the forces of denudation, these reefs give rise to stacks and headlands along the coast and mound-shaped hills in the interior. The latter are favorite sites for windmills. Concerning the Gotland reefs Twenhofel states,

> In general the coral masses offer greater resistance than do the surrounding or underlying rocks, so that in cliffs they project as salients or overhanging masses and in the fields as knolls, on the northward or stoss side of which, the side from which the ice came, the surrounding rock has all, or nearly all, been eroded away, while on the side opposite the direction of ice movement the protection of the coral masses has preserved to some extent the surrounding rock, which is generally a crystalline limestone. These knolls are called by the people "Klintar," and they constitute the hearts of the elevations of the island.[3]

For further information on the Gotland reefs see A. W. Grabau, references cited above; Herman Hedström, "The Stratigraphy of the Silurian Strata of the Visby District," 11*e Congrès Géologique International*, No. 20, Excursions B6, C_2 (C_3) (1910), 30 pp.; H. Munthe, "The Sequence of Strata in Southern Gotland," 11*e Congrès Géologique International*, Livret-Guide des Excursions, 1, No. 19, Excursions B6, C_2 (C_3) 1910), 57 pp.; W. H. Twenhofel, *Treatise on Sedimentation* (1926), pp. 225–26.

In his great classic, *The Silurian System*, Murchison mentions reefs, which he calls "ball-stones," in the Wenlock limestones near Wenlock, England. One klint in particular, called "Ippikin's Rock," is mentioned as a boss 50 or 60 feet high (p. 212). Tiddeman mentions "Reef Knolls" from the Carboniferous limestones of the Clithroe district, England,[4] and Hudson[5] in a very recent paper

[1] R. I. Murchison, "On the Silurian and Associated Rocks in Dalecarlia, and on the Succession from Lower to Upper Silurian in Smoland, Öland, and Gothland, and in Scania," *Quar. Jour. Geol. Soc. London* (Proceedings for June, 1846), Vol. III (1847), p. 20.

[2] Carl Wiman, "Über Silurische Korallenriffe in Gotland," *Bull. Geol. Inst. Upsala*, Vol. III (1896–97), pp. 311–26.

[3] W. H. Twenhofel, *op. cit.*, pp. 347–48.

[4] R. H. Tiddeman, "On the Concurrent Faulting and Deposit in Carboniferous Times in Craven, Yorkshire, with a Note on Carboniferous Reefs, *Rept. British Assoc.* (Newcastle-on-Tyne), (1889), pp. 600–603; *Congrès Géologique International Compte Rendu*, 4me sess. (1888), pp. 319–29.

[5] R. G. S. Hudson, "A mid-Avonian Reef Limestone and Conglomerate in the Craven Lowlands," *Geol. Mag.*, Vol. LXIV, No. 761 (1927), p. 506.

calls attention to hills in the Craven Lowlands, which he says are due to the development of reef limestone of Carboniferous age.

Walther[1] has pointed out the reef character of the structureless masses associated with the famous lithographic limestone deposits of Jurassic age in the Solenhofen district of Bavaria. These reef masses stand out in bold relief when the inter-reef "Plattenkalke" have been eroded away.[2]

Grabau, in his *Principles of Stratigraphy*, calls attention to reefs in various localities in Europe. Many of these reefs give rise to spectacular klintar, which are often surmounted by castles and ancient burgs. These klintar range from a few meters to as much as 100 meters or more in height.

An exhaustive examination of the literature would undoubtedly reveal many klintar of various ages throughout the civilized world. Many more have as yet probably been unnoticed by the geologist and physiographer.

SUMMARY

It will be seen from the foregoing discussion that the unreduced portions of organic reefs in northern Indiana, designated klintar because of their similarity to like features on the Island of Gotland, give rise to distinct topographic forms, which are duplicated in various places not only in our own country, but also in Canada, in England, and on the continent of Europe.

The reef mounds or klintar of the Wabash sluiceway have an interesting geologic and physiographic history. Initially they were built in the Niagaran seas as great stony masses in the formations about the border of the southern half of the Michigan Basin. These initial structural units in the Niagaran formations were then buried beneath younger strata. Following the close of the Paleozoic the younger overlying strata were removed and a few of the reef masses were brought out in topographic relief as klintar through the removal of the inter-reef strata. This old erosion surface was then buried beneath glacial drift as the Pleistocene glaciers transgressed it. By the close of Pleistocene time the glacial-flood waters had cut out

[1] Johannes Walther, "Die Fauna der Solenhofener Plattenkalke Bionomisch Betrachtet," *Festschrift zum Siebzigsten Geburrtstage von Ernst Haeckel*, Jena (1904).

[2] A. W. Grabau, *Principles of Stratigraphy* (1924), p. 438.

the Wabash sluiceway through bed rock and drift alike. Only a very few of the buried klintar were resurrected along the narrow sluiceway. Most of the klintar of northern Indiana came into existence during the excavation of the Wabash sluiceway as indicated by the frequent tongues of inter-reef rock that extend downstream from the klintar.

The klintar of northern Indiana are reef-rock hills or mounds. Some of them are in shape not unlike an inverted shallow bowl. Others are rocky masses of irregular contour, the upstream portion comprising a partially destroyed reef mass standing up as a bulwark against which came the glacial-flood waters that excavated the Wabash sluiceway. Low narrow tongues of unremoved inter-reef bed rock or glacial drift almost always extend downstream from the reef mounds or klintar proper. Still other klintar are low rocky mounds without any particular shape or contour, yet unreduced because of their superior resistance. The latter, gently swelling above the valley floor of the Wabash sluiceway, are frequently the sites of farm buildings and, being covered with trees, form a striking contrast to the prairie-like valley expanse that surrounds them.

Thus these klintar, initially reef masses of peculiar structure in geologic formations, have had an interesting physiographic development and history. Their shape or form has been determined in part by the superior resistance and unique structure of the stony reef masses and in part by the peculiar erosional forces to which they have been subjected. They stand today on a sluiceway floor of a past glacial flood, bearing the marks of a destroying assault which they bravely withstood.

SOME ISSUES IN CHESTER STRATIGRAPHY IN KENTUCKY AND ILLINOIS

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ABSTRACT

This paper is a contribution toward the settlement of a long-standing controversy concerning certain points in Chester stratigraphy in Kentucky and Illinois. The late Professor Weller correlated the Renault formation of Randolph County, Illinois, with both the upper part of the Ohara limestone and the lower part of the Gasper limestone, and also correlated the Bethel sandstone of western Kentucky with the Sample sandstone of Breckinridge County, Kentucky. He and his son, Dr. Marvin Weller, denied the validity of the name Gasper and used, instead, the hyphenated designation Renault-Paint-Creek. Professor Weller also questioned the suitability of the name Bethel for the sandstone unit so named. The present paper presents concrete evidence tending to disprove the views of the Wellers on the points mentioned. Certain characteristic species of fossils mark the lower part of the Gasper *beneath the Sample sandstone* and the same assemblage occurs in Christian and Caldwell counties, Kentucky, in the lower part of the typical "Tribune" limestone of Ulrich (for which the name Gasper was substituted), and *above the Bethel sandstone* and hence above the Ohara limestone which immediately underlies the Bethel sandstone in western Kentucky. Not one of the characteristic members of this fauna has ever been found in the Ohara limestone or below the horizon of the Bethel sandstone. From this it follows that the Bethel and Sample sandstones are not the same. Therefore the Renault formation cannot be the equivalent of both the Ohara, which is below the Bethel, and the "lower Gasper," which is above the Bethel. As it is admitted by the Wellers that the Gasper is an indivisible unit equivalent to the Renault and Paint Creek, and as the name is applied in accordance with the customary modern practice of giving a new name to two or more combined units, its validity cannot be fairly questioned.

In regard to the name Bethel, it is shown that the sandstone near Bethel school, now Crittenden Springs school, which Weller thought to be the lower part of the Cypress sandstone, is directly underlain by the Ohara limestone and therefore clearly Bethel, so that the name is entirely appropriate.

In a number of recent publications,[2] the late Professor Stuart Weller, who has contributed so much to our knowledge of the stratigraphy and paleontology of the Mississippi Valley, has, partly in collaboration with his son, J. M. Weller, expressed views as to certain matters of Chester stratigraphy and nomenclature in Illinois and Kentucky which seem to me to be at variance with the facts and which certainly bring into question the correctness of my own conclusions on those matters. While these differences doubtless are of

[1] Published by permission of the director, United States Geological Survey.

[2] "Geology of the Princeton Quadrangle," *Ky. Geol. Survey*, Ser. 6, Vol. X (1923); "Geology of the Cave-in-Rock Quadrangle," *ibid.*, Ser. 6, Vol. XXVI (1926); "Geology of Edmonson Co.," *ibid.*, Ser. 6, Vol. XXXVIII (1927).

relatively minor importance and are such as may easily arise between workers in the same field; yet, as silence on my part, which otherwise would be so much more desirable now, would be interpreted as acquiescence in views with which I am unable to agree, it seems that a presentation of the evidence for my own conclusions upon the questions at issue is permissible even under the present regrettable circumstances.

I wish to say, however, that this paper was planned soon after the publication of the report on the geology of the Princeton quadrangle in 1923 and long before Professor Weller's death; but, learning that he and his son were engaged in a survey of Edmonson County, Kentucky, its preparation was deferred in the hope that, by extending their investigations farther east, evidence would be discovered which would lead to a modification of Professor Weller's views so that they would agree with my own. Such a happy outcome of their eastern work, which would have been so satisfactory and would have made this paper unnecessary, was not realized, however, so that in the interest of scientific truth, as well as in justice to myself, I feel impelled to enter into this discussion of the case.

The principal matters at issue are, first, the relation of the Bethel sandstone of western Kentucky to the Sample sandstone of Breckinridge County; second, the validity of the name Gasper for the combined units Renault and Paint Creek formations; and, third, the relation of the Renault formation of the southwestern counties of Illinois to the upper part of the Ohara limestone of western Kentucky and to the lower part of the Gasper oölite of western, central, and eastern Kentucky.

The Wellers believe that the Bethel sandstone is the same as the Sample, while Ulrich and I have always regarded them as separate units; they claim that the Renault formation is the same as both the upper part of the Ohara and the lower part of the Gasper, while Ulrich and I correlate the Renault with the lower part of the Gasper only; and finally they believe that the name Gasper is not valid and should be abandoned. What is the equivalent of the Renault in western Kentucky has been a matter of discussion between Weller and Ulrich for a number of years. Weller has presented his argu-

ments for the correlations indicated above in the Kentucky reports cited and also in the "Geology of Hardin County, Illinois," *Bulletin 41 of the Illinois Geological Survey* (1920); and Ulrich has discussed the subject very fully in the "Mississippian Series of Western Kentucky," *Kentucky Geological Survey*, 1917, and in the *Bulletin of the Geological Society of America*, Vol. XXXIII (1922).

In order to prepare the reader for the discussion of the questions at issue, the following stratigraphic sections are given.

SECTION IN SOUTHWESTERN ILLINOIS—MONROE AND RANDOLPH COUNTIES

(After Weller, *Illinois State Geological Survey Monograph 7* [1914], pp. 24–26)

	Feet
Paint Creek formation:	
4. Limestone mainly	35
3. Shale, mostly red	25
Yankeetown formation:	
2. Limestone, hard, siliceous, or quartzite, cross-bedded, knotty, banded	20
Renault formation:	
1. Variable, limestone in more or less continuous layers, shale, variegated shale, and sandstone	40–100
Aux Vases sandstone (=Brewerville formation)	

SECTION IN CRITTENDEN COUNTY, KENTUCKY

(Some of the data in this section, such as descriptions of lithology and thicknesses, are from Weller, *Geology of the Cave-in-Rock Quadrangle*, but the arrangement is by the writer)

Cypress sandstone:	
8. Sandstone	100±
Paint Creek formation:	
7. Shale, mainly dark or gray, fissile, a little red shale below locally, also thin limestone below and thin sandstone with black shale partings above	20– 40
Bethel sandstone:	
6. Sandstone, thick-bedded in part cross-bedded and conglomeratic with quartz pebbles	40±
Ste Genevieve limestone:	
Ohara limestone member:	
5. Limestone with shale partings and a shaly bed 15 feet thick in lower part	40–100

	Feet
4. Conglomerate of limestone pebbles. (By Weller these beds, Nos. 4 and 5, are correlated with the Renault formation and given that name by him. See reports cited on p. 31.)	1
3. Limestone, thick-bedded, oölitic	0– 50
Rosiclare sandstone member:	
2. Sandstone	2– 20
Fredonia limestone member:	
1. Limestone, thick-bedded, gray, in part oölitic	250±

SECTION IN THE WESTERN PART OF CHRISTIAN COUNTY, KENTUCKY, ON THE ROAD FROM CERULEAN SPRINGS TO THE PRINCETON-HOPKINSVILLE PIKE, BEGINNING AT THE BRIDGE ACROSS MUDDY RIVER ABOUT 2 MILES NORTH OF CERULEAN

(Ulrich's type section of the "Tribune" limestone. See topographic map of the Dawson Springs Quadrangle)

Cypress sandstone:	
13. Sandstone, thin-bedded to shaly with a thin layer of red marl, to top of hill. *Archimedes confertus* in bottom	40±
Gasper oölite:	
12. Marl, mostly green, a layer of limestone and of red marl, *Archimedes* abundant, *Pentremites pyriformis, Talarocrinus, Pterotocrinus serratus, Cystodictya labiosa*	20
11. Limestone, partly oölitic, some white oölite, *Pentremites, Talarocrinus, Archimedes, Lyropora*, and other Bryozoa	30
10. Marl, green	2
9. Limestone, *Agassizocrinus, Pentremites* abundant, *Lyropora*	10
8. Limestone, *Pentremites*, no *Agassizocrinus* or large crinoid stems noticed	20
Marl, soft, green	3±
7. Limestone	10
6. Shale with limestone layers?	10±
5. Limestone, *Campophyllum gasperense, Pentremites godoni* Ulrich, *P. planus, P. pyriformis*, and large crinoid stems. These fossils were collected in the immediate vicinity of Ouerby's house, which is shown on the map of the Dawson Springs quadrangle on the west of the road to Cerulean about ¾ mile southwest of its intersection with the Princeton pike marked by the bench mark 555 feet. Same assemblage *below the Sample sandstone* of Breckinridge County	10±
Not exposed	20–30?

Feet

Bethel sandstone:

4. Sandstone. Lower 30 feet thick-bedded to massive; upper 10 feet thin bedded..... 40±

Ste Genevieve limestone:

Ohara limestone member:

3. Marl, green..... 8
2. Limestone, shelly. *Talarocinus de wolfi*, *Spiriferina subspinosa*, and other brachiopods and Bryozoa..... 2
   Talarocrinus de wolfi is unknown above the Ohara or above the Bethel sandstone
1. Limestone, thick-bedded, pure, to bed of Little Muddy River..... 20

(1, 2, and 3 are upper beds of Ohara.)

SECTION ON MCFADDEN CREEK, 8 MILES WEST-NORTHWEST OF BOWLING GREEN, WARREN COUNTY, KY.

Cypress sandstone:

Low slope with abundant sandstone débris

Gasper oölite:

4. Limestone, fossils scarce..... 60
3. Shale, fossils abundant..... 5
2. Limestone, thick-bedded, partly oölitic, fossils abundant, *Campophyllum gasperense*, *Pentremites godoni* Ulrich, *P. planus*, *P. pyriformis*. Typical lower Gasper assemblage. *P. planus* and *P. godoni* occur by the thousand..... 40

Hiatus—Bethel sandstone absent

Ste Genevieve limestone:

Ohara limestone member:

1. Limestone, thick-bedded, light gray, layers are a compact mass of fossil fragments, to bottom of slope. *Talarocrinus buttsi*, *Pentremites princetonensis*. The species of fossils named are unknown above the Bethel sandstone..... 40

SECTION AT SAMPLE, BRECKINRIDGE COUNTY, KENTUCKY

(The section of the Sample sandstone and of the beds below was taken on the railroad ½–2 miles east of Sample; the Ste Genevieve is exposed in the quarry at New Mystic, 2 miles east of Sample. The upper part of the section was taken along the road directly north of Sample Station. This road is now abandoned)

	Feet	Inches
Hardinsburg sandstone:		
26. Sandstone, flaggy, to top of exposure	20	...
Golconda formation:		
25. Shale	10	...
24. Limestone, Bryozoa, especially *Archimedes*, abundant. *Pentremites* and brachiopods	30	...
Cypress sandstone:		
23. Shale, green clay, with red shale layers. This is a local facies of the Cypress sandstone. Not far both to south in Kentucky and to north in Indiana, this interval is sandstone with the same beds above and below as those above and below the shale here.	50	...
Gasper formation:		
22. Limestone, coarsely crystalline, shelly and reddish at top. *Chonetes chesterensis*, *Productus inflatus* (abundant), *Martinia* sp.?, *Spirifer pellaensis?* Persistent horizon recognized by Weller and all others as top of Paint Creek formation. Beech Creek limestone of Malott*	11	...
21. Shale, red 20. Shale, soft, dark } Elwren shale of Malott	10 18	... ...
19. Limestone, thick-bedded, coarse-grained. *Pentremites* and *Agassizocrinus* abundant; *Archimedes laxus*, *Lyropora*, *Productus*, *Composita*. Reelsville limestone of Malott, but much thicker here than in Indiana	30	...
18. Sample sandstone member: Sandstone, generally thick-bedded, partly cross-bedded. Locally, as at Sample Station, sandy shale and thin sandstone 12–15 feet thick but increases in ½ to 1 mile to heavy sandstone 25–40 feet thick	40	...
17. Limestone, thick-bedded, partly oölitic, Beaver Bend limestone of Malott	10–13	...
16. Shale, marly	2	...
15. Limestone	.....	10
14. Clay	.....	2½
13. Coal	.....	8
12. Sandstone, soft, gnarly, ferruginous, Stigmaria†	.....	8

* Clyde A. Malott, "The American Bottoms Region of Eastern Greene County, Indiana," *Ind. Univ. Studies*, Vol. VI, "Study, No. 40 (March, 1919); E. R. Cumings, *Handbook of Indiana Geology*, Part IV (1922), pp. 514–16. Malott has recognized in the equivalent of the Gasper in Indiana the following lithologic units in ascending order: Paoli limestone, Mooretown sandstone, Beaver Bend limestone, Sample sandstone, Reelsville limestone, Elwren sandstone and shale, and Beech Creek limestone.

† *Dictyophlois reticulata* Foerste, *Bull. Torrey Bot. Club* No. 42 (January 20, 1916), pp. 675–77, pl. 33.

	Feet	Inches
11. Clay, sandy	1	10
Beds Nos. 11–16 correspond to the Mooretown sandstone of Malott,‡ reaching a thickness of 60 feet of massive sandstone as at New Amsterdam, Indiana.		
10. Limestone, partly compact, partly oölitic, *Campophyllum gasperense* 2–5 feet below sandy fire clay, No. 11; *Pentremites godoni* Ulrich, *P. planus, P. pyriformis; P. symmetricus, P. welleri, Talarocrinus* of undetermined species. Most of these were collected ½ mile south of Sample	17	...
9. Shale with thin limestone layers; *Talarocrinus patei*	.....	8
8. Limestone, light-gray compact	2	...
7. Shale with limestone layers. *Spirifer pellaensis?* and *Composita trinuclea abundant*	2	...
6. Limestone, coarsely crystalline	1	...
5. Limestone, light-gray compact, partly oölitic	2	...
4. Oölite full of well-rounded oölite pebbles making a kind of conglomerate; also contains a good sprinkling of quartz grains. This bed is persistent throughout Breckinridge County and may represent the Bethel sandstone	1	6
Ste Genevieve limestone:		
3. Limestone, thick-bedded, blue, oölitic	4	...
2. Clay, blue, lumpy	1	6
1. Limestone, tick-bedded, blue and gray, oölitic and compact (lithographic) texture, *Lithostrotion harmodites* at bottom and perhaps higher. May include a representative of the Ohara member in upper part. Exposed in quarry at New Mystic	50	...

‡ E. R. Cummings, *op. cit.*, p. 515.

The interpretations placed by the Wellers and by Ulrich and the writer upon the sections given above is shown in Table I. The main differences in these two interpretations are, first, that Weller correlates the Renault with both the upper Ohara and the lower part of the Gasper limestone, and, second, that he correlates the Bethel sandstone with the Sample sandstone, while Ulrich and the writer correlate the Renault with the lower Gasper only and regard the Bethel sandstone as a different bed from the Sample. Professor Weller's views are fully set forth in the following quotation,[1] the italicized passages by the present writer.

[1] *Geology of the Princeton Quadrangle, Kentucky*, pp. 49–51.

TABLE I

Southwest Illinois, Monroe and Randolph Counties	North of Cerulean Springs, Kentucky	Bowling Green, Kentucky	Sample, Kentucky
		Weller's Interpretation	
Cypress sandstone	Cypress sandstone	Cypress sandstone	Cypress sandstone
Paint Creek	Paint Creek (upper Gasper)	Paint Creek (upper Gasper)	Paint Creek (upper Gasper)
Yankeetown formation	Bethel sandstone	Absent	Sample sandstone
Renault	Renault (upper Ohara)	Renault (lower Gasper)	Renault (lower Gasper)
Ste Genevieve	Ste Genevieve	Ste Genevieve	Ste Genevieve
		Interpretation of Ulrich and Butts	
Cypress sandstone	Cypress sandstone	Cypress sandstone	Cypress sandstone
Paint Creek formation	Gasper formation	Gasper formation	Gasper oölite: ("Upper Gasper")
Yankeetown chert			Gasper oölite: Sample sandstone member
Renault formation			Gasper oölite: ("Lower Gasper")
Hiatus or Aux Vases sandstone	Bethel sandstone	Hiatus	Hiatus
Ste Genevieve limestone	Ste Genevieve limestone: Ohara limestone member Fredonia oölite member	Ste Genevieve limestone: Ohara limestone member Fredonia oölite member	Ste Genevieve limestone: Ohara limestone member, thin representative? Fredonia oölite member

In their more recent writings, both Butts and Ulrich have used the name Gasper in place of Tribune, because of the unfortunate choice of the latter name. The typical Tribune is the same as the Paint Creek of the Princeton Quadrangle, but the typical Gasper is exposed farther east in Kentucky than the Princeton Quadrangle, and as described consists of two limestone members separated by the Sample sandstone member. The whole of the more typical Gasper is correlated by these authors with the Renault and Paint Creek limestones together of the western Illinois section, *a correlation which seems to be wholly justified*. The same authors consider the Paint Creek of the Princeton region to be the equivalent of the whole of the Gasper farther east and consequently must find the equivalent of the Sample sandstone member within the 100 feet of the formation. In western Christian County, along the Princeton-Hopkinsville Pike, "Ulrich's type locality of the Tribune limestone," Butts has designated a clay bed two to three feet thick as the equivalent of the Sample sandstone of Breckinridge County,[1] and in this manner he is able to make two divisions of the Gasper such as are present in the more typical section. There is no reason whatsoever for dividing this "typical Tribune limestone" section, so far as the paleontological evidence is concerned, and the whole interpretation is based on the misconception of the true relationship of the Sample and Bethel sandstones, *which are really exactly equivalent*. In Breckinridge County the true Renault fauna is present beneath the Sample sandstone just as it is present beneath the Bethel sandstone in the region east of Princeton, and the Paint Creek fauna is present in beds overlying these two sandstones in the two regions. Both Butts and Ulrich have assumed without reason that the "Upper Ohara" in the Princeton region is older than the Renault, therefore it is necessary for them to find some equivalent for the Renault in the formation they now call Gasper. The same men have recently determined that the Renault ("Upper Ohara") in Union County, Illinois, is Paint Creek in age, a determination which is proven to be incorrect by reason of the beds having been actually traced and mapped in detail from the undisputed ("Upper Ohara") farther east in Illinois, to the outcrop which they examined in Union County.

Both paleontological and stratigraphical evidence confirm the exact correlation of Ulrich's "Tribune limestone" of the section east of Princeton, with the Paint Creek formation of southern and southwestern Illinois, and with the upper division of the Gasper limestone of Breckinridge County, Kentucky.

In the recently published report on Edmonson County, by J. M. Weller,[2] essentially the same views are advanced:

The Renault-Paint Creek Limestone of Edmonson County is *equivalent to Ulrich's Upper Ohara of the Ste. Genevieve* combined with the limestone for

[1] My statement is: "While this clay bed appears to lie at the horizon of the sample sandstone it has not been established beyond doubt that such is the fact" (*Miss. Ser. Western Ky.*, p. 73, top). C. B.

[2] *Geology of Edmonson County, Kentucky*, pp. 109–10.

which he proposed the name Tribune. It is also the limestone to which Butts and Ulrich have applied the name Gasper. . . . .

The correlation of the Renault formation with both the upper Ohara and the lower part of the Gasper lies at the bottom of the differences between the Wellers and Ulrich and myself in the stratigraphic alinement of the concerned formations. If it can be shown that the Ohara and lower part of the Gasper are not the same, the position of the Wellers becomes untenable; and it is the principal object of this paper to show that they are not the same.

In the section at Sample, Breckinridge County, the type locality of the Sample sandstone, there occur in the Gasper, *beneath the Sample sandstone*, the fossils *Campophyllum gasperense*, *Pentremites godoni* Ulrich, *P. planus*, *P. pyriformis*, *P. symmetricus*, *P. welleri*, *Talarocrinus patei*, and parts of large crinoid stems up to more than ½ inch in diameter. In the section north of Cerulean given above, which is Ulrich's type section of the "Tribune" limestone, *Campophyllum gasperense*, *Pentremites godoni* Ulrich, *P. planus*, *P. pyriformis*, and pieces of large crinoid stems identical with those collected at Sample have been collected by the writer from *above the Bethel sandstone*. *Pentremites welleri* also is listed by Ulrich from the lower part of the Gasper ("Tribune") of the immediate vicinity. Also Ulrich lists *Talarocrinus ovatus* and *T. symmetricus* from the same horizon in the region; and these, together with *T. sexlobatus* and *T. inflatus*, are constant associates of the other fossils of this zone throughout Kentucky, Tennessee, Alabama, and Virginia. Bases of *Talarocrinus* were seen in the section north of Cerulean, but no identifiable specimens were obtained. The fossils from north of Cerulean were all collected in the immediate vicinity of Ouerby's house about 500 feet west of the road which, as shown near the southwestern corner of the map of the Dawson Springs quadrangle, joins the Princeton pike at the point marked by the bench mark 555. A special visit was made by the writer to this locality in 1924 for the purpose of studying this section. A continuous section was made starting at Muddy River about 2 miles south of Ouerby's. At Muddy River a bluff or low cliff of Bethel sandstone begins and continues for about ½ mile north along the road. The sandstone is almost continuously exposed, dipping slightly northward and descending below the alluvium of Wallace Creek about on the south

margin of the Dawson Springs quadrangle. Ouerby's house is about ½ mile farther north, and the dip of the Bethel sandstone is so slight that it could be hardly more than 20 or 30 feet below the level of the house which, according to the map, is located about 20 feet above Wallace Creek. There is not the slightest uncertainty as to the relations of the *Campophyllum* zone, as it may be called, to the Bethel sandstone at this locality, or to the Sample sandstone in Breckinridge County. *It is above the Bethel and below the Sample.* At Sample the coral is just below the Stigmaria-bearing clay, No. 11, of the section at Sample. It can be seen *in situ* on the south side of a low bluff just north of Sinking Creek about ½ mile south of Sample and perhaps ¼ mile east of the road going south from Sample and crossing Sinking Creek by bridge at the Falls of Sinking. The bed in which the coral occurs is about 40 feet above the level of Sinking Creek, in the bed of which, at the bridge just mentioned, what is believed to be the Fredonia member of the Ste Genevieve limestone is exposed. At Webster quarry, 2 miles west-northwest of Irvington, Breckinridge County, and 9 miles east of Sample, *Lithostrotion harmodites* and *Platycrinus penicillus* occur in abundance 70 feet below the Stigmaria-bearing clay, so that the horizon of *Campophyllym*, which is about 5 feet below the Stigmaria clay, is not more than 65 feet above the Fredonia member of the Ste Genevieve, at that place, and is probably less than that, for the layers carrying the Fredonia fossils at Webster quarry may lie as much as 15 feet below the top of the Fredonia. The *Campophyllum* zone, with the same assemblage of fossils as that given in the preceding lists, occurs throughout Kentucky as far west as eastern Caldwell County, that coral having been observed and collected in the same position with respect to the Ste Genevieve at the following places: west of Smith's Grove, about 7 miles west of Bowling Green on McFadden Creek, and at Russellville. This fauna too is persistent across Tennessee west of the Cumberland Plateau into northern Alabama and extends beneath the Appalachian Plateau into southwestern Virginia. Specimens of *Campophyllum gasperense* associated with *Pentremites godoni* Ulrich were recently found by the writer just east of the plateau escarpment in Tazewell County, Virginia; and *Campophyllum* is listed by Girty in the report on Tucker County, West Virginia, by the West Virginia Geological Survey (pp. 456, 473).

Campophyllum gasperense is a proliferous coral of bushy habit of growth. It is illustrated and described in the "Mississippian Series of Eastern Kentucky," *Kentucky Geological Survey*, Ser. 6, Vol. VII (1922), pp. 136, 162–65. (See also figs. 1–9 at end of this paper.) This fossil is unique in the Chester group and could only be confused with *Lithostrotion proliferum* of the St. Louis limestone, from which it is easily distinguishable by the flat bottom of its calyx, whereas the *Lithostrotion* has a conical protuberance in the bottom of the calyx. Owing to its distinctive features, its wide geographic distribution and narrow vertical range, and its common occurrence throughout its geographic province, it is one of the best and most reliable horizon-markers in the entire Mississippian series. Throughout the entire area of its known distribution it occurs about 25–40 feet above the bottom of the Gasper, and it has never been found at any other horizon except possibly at its extreme southern range in Alabama, where it seems to occur in the basal 10–20 feet of the Gasper. Its presence alone in western Christian County, Kentucky, in the lower part of Ulrich's type section of the "Tribune" limestone and above the Bethel sandstone is sufficient to establish the identity of that part of the "Tribune" with the lower part of the Gasper. And this determination is made doubly sure by the additional fact that neither the *Campophyllum* nor a single one of its associated species named above has been found in the Ohara limestone of Western Kentucky where the "Tribune" (Gasper) and Ohara occur in superposition in the same sections, the Bethel sandstone intervening. With the exception of a single small specimen of an otherwise unknown species, *Pentremites praematurus* Ulrich, "Mississippian Series of Western Kentucky," Pl. 2, Fig. 20, *Pentremites* with depressed ambulacral areas, typified by *Pentremites godoni* Ulrich (*op. cit.*, Pls. 6–9), are unknown from beds older than the lower part of the Gasper. Other constant associates of the *Campophyllum* are *Talarocrinus sexlobatus*, *T. symmetricus*, *T. inflatus*, and *T. ovatus*. They are abundant with *Campophyllum* in the lower part of the Gasper at Russellville, Kentucky, not very distant from Cerulean. None of these species is known anywhere below the Bethel sandstone or its horizon. In testimony to this fact I cite Professor Weller's Ohara lists in the various publications mentioned at the beginning of this paper as well as Ulrich's lists in the "Mississippian

Series of Western Kentucky," the lists of both authors being based upon very extensive collections. These associated fossils, including the *Campophyllum*, are absent from the Ohara for the simple reason that they were not in existence at the time of its deposition or had not yet arrived in the Mississippian seas of the Mississippi Valley region. The *Campophyllum* fauna marks unmistakably one and the same horizon all the way from Breckinridge County to eastern Caldwell County and is incontestably post-Bethel and post-Ohara but pre-Sample.

The evidence is thus conclusive that the lower part of the Gasper formation is not the equivalent of any part of the Ohara limestone but that the latter is an older and underlying formation. From this it follows that the Renault formation cannot be equivalent to any part of the Ohara and at the same time be equivalent to the lower part of the Gasper. And as everybody, including the Wellers, is agreed that the Renault is equivalent to the lower part of the Gasper, that correlation is to be accepted as correct. This correlation is suggested by Weller in the *Geology of Hardin County, Illinois* (1920), p. 175; and reiterated by him in the *Geology of the Princeton Quadrangle, Kentucky* (1927), p. 50. It is also accepted by J. M. Weller in the *Geology of Edmonson County, Kentucky*, bottom of p. 109 and top of p. 110.

The evidence set forth above also proves that the Bethel sandstone, which is below, and the Sample sandstone, which is above, the lower part of the Gasper cannot be the same, as claimed by Professor Weller. It also disproves Weller's claim (*Geology of the Princeton Quadrangle, Kentucky*, p. 441) that the Gasper of eastern Caldwell and western Christian counties corresponds only to the Paint Creek, by showing that in that area the lower part of the Gasper, correlated with the Renault, is present and constitutes the lower half or so of the typical "Tribune." The Gasper maintains its integrity as a limestone westward into Caldwell County, but between that locality and Crittenden County undergoes a complete change of facies to a dark shale, perhaps with loss of its lower part, so that the shale may represent only the Paint Creek formation.

As the validity of the name Gasper has been denied either expressly, as by J. M. Weller, or by implication, by Professor Weller,

in his various Kentucky reports, a few words upon that subject are justifiable. Mr. J. M. Weller says:

> The name Gasper has not been used in this report because of the mistaken interpretation of the section by the author of the name, and because if applied strictly as a substitute for the older Tribune, as it was intended, it has no validity, the name Paint Creek having several years priority. The hyphenation of the names Renault and Paint Creek seems to be altogether the wiser plan to pursue in this case, since this usage clearly shows the relationship of the limestone to the Chester section elsewhere.[1]

Also, he says:

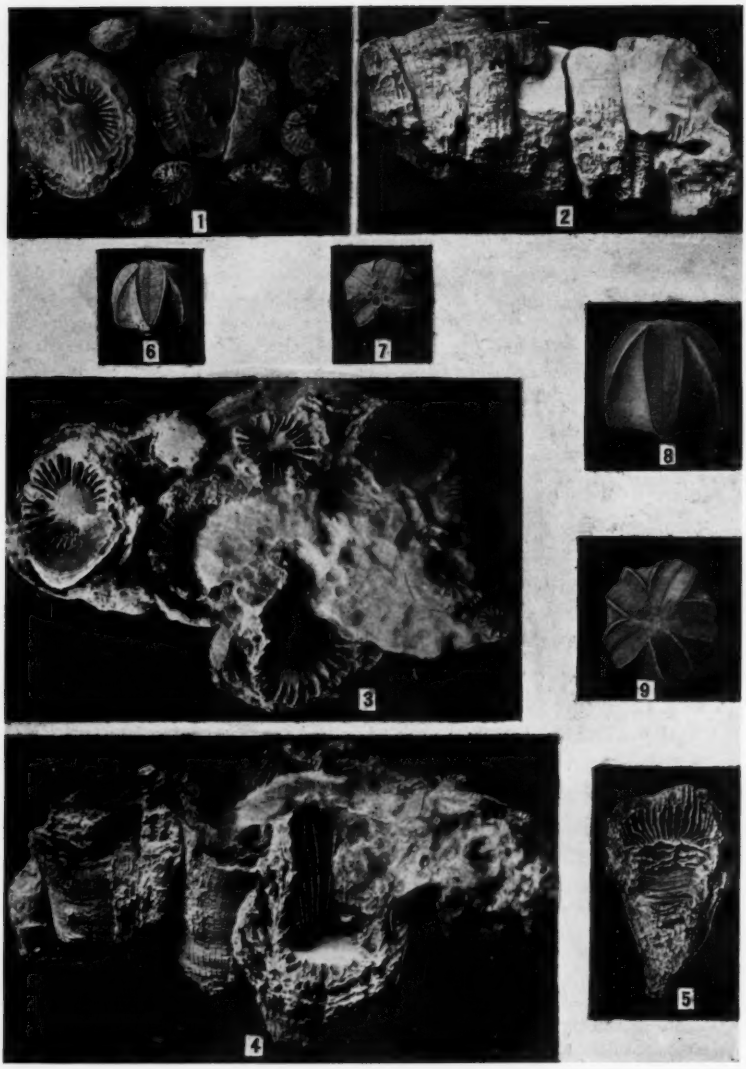
> In Edmonson County . . . . continuous limestone sedimentation prevailed from the beginning of Renault [lower Gasper] to the end of Paint Creek time, and, because of the lack of any lithologic or paleontologic means of differentiating these formations, they have been mapped and will be considered in this report as a single unit.[2]

The words in brackets in the foregoing quotation were added by the present writer. It is to be noted that Weller recognizes that, throughout most of its extent, the Gasper is a predominantly oölitic limestone unit which, except where the Sample sandstone is present in its midst, is not easily susceptible of subdivision. To this combined unit the name Renault–Paint Creek is applied contrary to the usual modern practice of using new names for combined units or for each of the parts of a subdivided unit. As the name Gasper is applied in accordance with current practice in the first case, i.e., for the combined units Renault and Paint Creek, as admitted by Weller, its validity does not seem fairly open to question. If any further support for the validity of the name were needed, it has been supplied in the last preceding quotation in which the fact that the typical Gasper is a lithologic unit and indivisible is admitted.

There is just one other matter that I wish to discuss. In the geology of the Cave-in-Rock quadrangle, in describing the Bethel sandstone, Weller says:

> Butts' name for the formation is an unfortunate choice because in the type locality the line of demarcation between the Bethel and Cypress sandstones is not exposed. In the bluff back of Bethel School no actual exposure of the Bethel sandstone can be seen—the massive sandstone ledges which were believed to be a part of the Bethel by Butts being the lower portion of the Cypress sandstone.[3]

[1] *Op. cit.*, p. 110. [2] *Ibid.*, p. 103. [3] *Ibid.*, p. 30, bottom.



FIGS. 1–9

DESCRIPTION OF FIGURES 1–9

(All figures natural size)

Characteristic fossils of the lower part of the Casper formation from Breckinridge and Christian counties, Kentucky.

FIGS. 1–5.—*Camophyllum gasperense.* The specimen of Figure 1, top view, and Figure 2, side view, is from ½ mile south of Sample, Breckinridge County, Kentucky, where it occurs in the lower part of the Gasper oölite 20 feet *below the Sample sandstone member.* Figures 3–5 from the lower part of the Gasper oölite and about 20 feet *above the Bethel sandstone* at Ouerby's place (see text) in the western part of Christian County, Kentucky. This is the very type locality of Ulrichs' "Tribune" limestone, in the lower part of which the coral occurs.

FIGS. 6–9.—*Pentremites godoni* Ulrich. Figures 6–7 from Ouerby's place (see above). Figures 8–9 from ½ mile south of Sample (see above). At both places it occurs in the lower part of the Gasper formation in immediate association with *Campophyllum* and several other species of *Pentremites* and several species of *Talarocrinus,* all equally characteristic of the lower Gasper horizon and unknown below it. In fact, with the single exception noted on page 41, *Pentremites* of the type of *P. godoni* Ulrich, that is, with depressed or concave anbulacral areas, as shown in Figures 6–9, are unknown from horizons older than the lower Gasper. They do not occur in the Ohara limestone, which immediately underlies the lower part of the Gasper (Ulrich's "Tribune" limestone) in Christian and Caldwell counties, Kentucky. This proves conclusively that the lower part of the "Tribune" is equivalent to the lower part of the Gasper and younger than the Ohara, also that the Bethel sandstone, being *below* the lower Gasper, is not the same as the Sample sandstone which is *above* the lower Gasper.

It is true that in a considerable area in this general region extending north of Ohio River into the southern part of Battery Rock Township, Illinois, the Bethel and Cypress sandstones are nearly or quite continuous through the practical disappearance of the Paint Creek formation normally separating them. So it is true that I supposed all the sandstone on the hill back of Bethel School to be Bethel. Weller was mistaken, however, in referring the sandstone of the low cliff back of Bethel School to the lower part of the Cypress. This sandstone, of which about 30 feet is exposed, includes a conglomeratic layer 10 feet thick with quartz pebbles up to ½ inch in diameter. The Bethel is the only sandstone in the Chester of that region known to be conglomeratic except possibly the Rosiclare sandstone at one place. Furthermore, the sandstone of the ledge is immediately underlain by 80 feet of shale and limestone which is mostly exposed. The limestone at top is cherty like the top of the Ohara generally. The shale still lower carries, among other fossils, *Amplexus geniculatus,* a characteristic upper Ohara fossil of the region; also *Meso-*

blastus glaber, more common in the Ohara than elsewhere; and a species of *Glyptopora*. No effort was made to make a full collection because of the fact that the beds are Ohara was quite evident. Below the fossiliferous shale is more limestone. Still lower, by the roadside at the foot of the slope, the Fredonia oölite with *Platycrinus penicillus* crops out.

The section of the Ohara and Bethel is exposed on the slope directly above and slightly northeast of the intersection of the road going west, which intersection is about 500 feet southwest of Bethel School, now named Crittenden Springs School on the topographic map of the Cave-in-Rock quadrangle.

So, although I included in my conception of the Bethel the overlying Cypress sandstone shown only by rock waste on the top of the hill just northeast of Bethel School, it is nevertheless true that the conspicuous ledge at the base is really a fair representation of the unit, to which only, the name Bethel was intended to apply.

"TRIASSIC-JURASSIC 'RED BEDS' OF THE ROCKY MOUNTAIN REGION": A DISCUSSION[1]

JOHN B. REESIDE, JR.
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ABSTRACT

The conclusion drawn by Professor E. B. Branson in a recent paper on the "Red Beds" of the Rocky Mountain region that parts of these beds are marine is considered likely. The conclusion that there exists no basis for subdivision of the beds is not accepted, and a division of the Mesozoic part into Lower Triassic, Upper Triassic, and Jurassic units is advocated. The conclusion that no eolian deposits are present likewise is not accepted, and the interpretation of important parts of the Jurassic unit as eolian is advocated. Disagreement is expressed with much of Professor Branson's correlation table, and a substitute is offered. His paleographic map is considered invalid because based on erroneous correlations and interpretations of conditions.

GENERAL STATEMENT

Professor E. B. Branson's recent paper on the "Triassic-Jurassic 'Red Beds' of the Rocky Mountain Region"[2] bears upon specific and general problems of great interest. His observations are stated to cover nearly the whole region of occurrence of red beds of Mesozoic age, and his conclusions are far-reaching. Branson presents a map showing the distribution of red beds in the Rocky Mountain region[3] and a table showing his age assignments and correlations of the included formations.[4] He states, in summary,[5] that no adequate basis is available for the separation of the lower from the upper red beds, that the vertebrate fossils known are of little value in correlation, that no appreciable part of the red-bed sequence from Permian to Jurassic is eolian in origin, and that various features of the red beds indicate a marine origin for the major part of them and a subaerial origin for other minor parts. He also presents a paleogeographic map of central North America in Upper Triassic time[6] which shows an inland sea covering northwestern Texas, northern New Mexico and Arizona, eastern Nevada, southeastern Idaho, all of

[1] Published by permission of the director of the U.S. Geological Survey.

[2] *Journal of Geology*, Vol. XXXV (1927), pp. 607–30.

[3] *Ibid.*, p. 608, Fig. 1.

[4] *Ibid.*, p. 610, Fig. 3.

[5] *Ibid.*, pp. 607, 630.

[6] *Ibid.*, p. 609, Fig. 2.

Wyoming and Utah, western Colorado, southern Montana, and western Nebraska and South Dakota; a large river system draining the central United States and entering the sea in northwestern Texas; and a narrow channel in Nevada connecting with the open ocean to the west.

Such a synthesis of data pertaining to the "Red Beds" as Branson has attempted is welcome indeed, but to be satisfactory and useful it must be fairly complete and must account, in its broad view, for various local features, or at least must not stand in violent conflict with them. It is the present writer's opinion, based in part on the literature but in greater part on personal observation during fifteen summers of field work in Wyoming, Colorado, Utah, and northern Arizona and New Mexico, that at many points Professor Branson has failed to accomplish this result. Much still remains to be learned, of course, but much has been accomplished that should be taken into account in a general consideration of the "Red Beds."

MARINE ORIGIN OF RED BEDS

With the main thesis of Branson's paper, that large thicknesses of the red beds of the Rocky Mountain region present characteristics explainable only by the assumption of deposition in a very large body of water, probably saline, the writer has much sympathy. In such formations as the Moenkopi of southern Utah, the undifferentiated Woodside and Thaynes of the eastern Uinta Mountains, and the Chugwater of central Wyoming (where it includes only the beds from the top of the Permian deposits to the base of the "Popo Agie beds" or Jelm formation), the gradual transition laterally from fossiliferous marine red and non-red sediments into unfossiliferous red beds, the widespread regularity and parallelism of bedding in great thicknesses of rock, the lack of coarse materials, etc., do not harmonize well with a postulate of fluviatile origin of the deposits. The contrast is striking between the formations named and such deposits as the Chinle formation, the Jelm formation, and the Dolores formation, in which very irregular bedding, non-persistence of minor units, coarse débris, remains of terrestrial vegetation, crocodiles, dinosaurs, and fresh-water invertebrates suggest a fluviatile origin. Some recent writers have preferred to interpret all red beds as a product of

"continental" sedimentation, but red beds are so varied in their characters—even in coloring—that a single explanation of origin seems entirely inadequate to account for all of them. One might as well attempt to explain all sandstones by the postulate of a single set of conditions.

CORRELATIONS

The correlation table given by Branson,[1] incorporating in compact form important parts of the paper, seems to the present writer in large part inconsistent with the best existing data. It presents an interpretation much too simple to account for the facts. A large amount of information—of unequal value, to be sure, but mostly usable—has accumulated over a considerable period of years. Recent detailed field work has checked and corrected much of this, has added new data, and has afforded correlations between Utah and western Colorado, between Wyoming and eastern Colorado, between parts of Wyoming, and between southeastern Idaho and adjacent areas in the main so well founded as to seem unimpeachable. The writer has attempted in the following paragraphs to give a brief review of the conclusions reached in this work, together with remarks on some other areas, and has presented them in graphic form in Figure 1.

Arizona, southern and eastern Utah, and southwestern Colorado.—The section in northern Arizona and southern and eastern Utah has received much attention and is very well worked out.[2] It may well serve, therefore, as a sort of standard section. That in southwestern Colorado is also well known;[3] and the relations of the formations to

[1] *Ibid.*, p. 610, Fig. 3.

[2] Recent publications on this region include: W. T. Lee and Others, "Possibility of Finding Oil in Southeastern Utah and Southwestern Colorado," *U.S. Dept. Interior Memo. for the Press*, March 30, 1926; A. A. Baker and Others, "Geology and Oil in Southeastern Utah," *U.S. Dept. Interior Memo. for the Press*, July 29, 1927; A. A. Baker and Others, "Notes on the Stratigraphy of the Moab Region, Utah," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XI (1927), pp. 785–808; James Gilluly and J. B. Reeside, Jr., "Sedimentary Rocks of San Rafael Swell and Some Adjacent Areas in Eastern Utah," *U.S. Geol. Surv. Prof. Paper 150* (1928), pp. 61–110. Many other papers bearing on the region are cited in the papers just listed, among the more important later works being those by Gregory, Emery, Dake, Longwell, Miser, and Prommel.

[3] Whitman Cross and Others, *U.S. Geol. Surv. Geol. Atlas*, Folios 57, 60, 120, 130, 131, 153, 171, and other papers.

those in Utah are in the main clear, though several lesser points are still in doubt. In the light of the accumulated information now in hand it is difficult to justify the interpretation set forth by Branson in columns 2 and 3 of his Figure 3.

In northern Arizona and southern Utah the section includes, in ascending order: Moenkopi formation, unconformable chocolate to

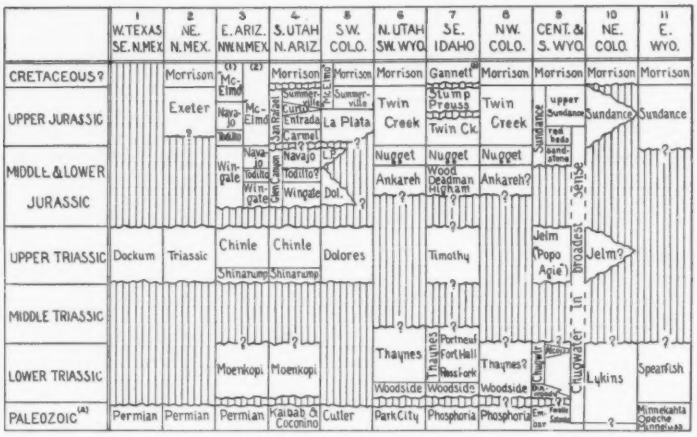

FIG. 1.—Correlation table of Triassic and Jurassic formations of the Plateau region, the Rocky Mountain region south of Montana, and parts of the Great Plains region, as interpreted by John B. Reeside, Jr. The vertically ruled areas indicate absence of sediments. Queries (?) on boundaries indicate doubt as to exact position. In column 3 the small columns (1) and (2) indicate alternative views of correlation. Footnote (*a*): Exact equivalence of formations on the line headed Paleozoic is not intended. Footnote (*b*): Gannett group probably includes much more than equivalents of Morrison formation.

red-brown, ripple-marked, thinly and evenly bedded sandstone and shale containing marine limestone members that thicken westward, Lower Triassic; Shinarump conglomerate, unconformable sandstone and conglomerate of siliceous pebbles, probably Upper Triassic; Chinle formation, conformable red and greenish sandy mudstone, sandstone, and limestone conglomerate, all irregularly bedded, Upper Triassic; Glen Canyon group, unconformable, probably Jurassic, containing three formations (Wingate sandstone, gray to red, thick, cross-bedded; Todilto(?) formation, thin-bedded red sandstone,

shale, and minor limestone; and Navajo sandstone, gray-white to light brown, thick, cross-bedded, containing occasional thin limestone lenses); San Rafael group, possibly unconformable, Upper Jurassic, containing four formations (Carmel formation, westward a marine, fossiliferous limestone, shale, and gypsum series, eastward a barren, red, earthy thin-bedded sandstone with bedding contorted; Entrada sandstone, westward a red, earthy, evenly bedded sandstone, eastward a thick, cross-bedded, gray-white to light pinkish-brown sandstone much like Navajo; Curtis formation, westward a light-colored, marine, fossiliferous grit and sandstone, fading eastward into the overlying unit; and Summerville formation, chocolate to red, very thinly and evenly bedded sandstone with crusts of silica); Morrison formation, gray to brown conglomerate and sandstone, and variegated shale containing dinosaur bones, doubtfully Cretaceous.

In southwestern Colorado the section includes, in ascending order: Dolores formation, unconformable, with lithology like that of the Chinle formation, Upper Triassic and possibly Jurassic; La Plata sandstone, unconformable, with lithology much like that of Navajo and Entrada and containing a thin limestone member near the middle, Jurassic; "McElmo" formation of the literature, unconformable, with basal part red and now assigned to the Summerville, and with upper part now assigned to the Morrison.

The Moenkopi formation does not extend into Colorado. The Shinarump conglomerate, Chinle formation, Wingate sandstone, and Todilto(?) formation seem to occupy the interval of the Dolores formation and were so identified by Cross, though some difference of opinion now exists as to whether Wingate and Todilto(?) extend as far eastward as the typical area of the Dolores, and it may be found equivalent there to Shinarump and Chinle only. The La Plata sandstone of Colorado, originally traced into eastern Utah by Cross and identified by him as including the three formations now named Navajo, Carmel, and Entrada, is seemingly the equivalent of these sandstones, though there is some doubt that the Navajo extends as far eastward as the area of the typical La Plata sandstone, and it may be found chiefly equivalent there to Entrada. Branson recognizes only two large sandstone units, though there are three, and

correlates them with the Vermilion Cliff group of Powell, which is, however, only the Wingate sandstone. The base of the Shinarump, the base of the Chinle where Shinarump is not recognized, and the base of the Dolores mark a widespread unconformity, the significance of which has been completely missed by Branson. The beds immediately beneath it belong to the Lower Triassic Moenkopi formation in east-central Utah and to the Permian Cutler formation in extreme eastern Utah and western Colorado. The Shinarump is conformable with the Chinle formation, which contains, as does the Dolores, vertebrate and fresh-water invertebrate remains usually accepted as Upper Triassic. Strong angular discordance at some localities beneath the Shinarump, and Chinle where Shinarump is not recognized, serves to strengthen sharp differences in lithology and fauna and makes it highly probable that a considerable time interval, perhaps most of the Middle Triassic, is unrepresented in the section. The La Plata sandstone has always been considered Jurassic, an assignment now definitely established for the part found equivalent to the Entrada sandstone (possibly the whole in the San Juan Mountains in Colorado). The age of the Glen Canyon group is not definitely determinable, though its resemblances are with the overlying Upper Jurassic much more than with the underlying Upper Triassic. Its known fossils include, in addition to dinosaur tracks, several species of *Unio* and some indeterminate plant remains, possibly ferns. Such structural evidence as there is agrees with lithology in associating the group with the later rather than with the earlier deposits, and its age is therefore stated as Jurassic(?). The writer believes the group best placed in the Jurassic without query and has so shown it in Figure 1.

Eastern Arizona and northwestern New Mexico.—The relations between northern Arizona, on one hand, and eastern Arizona and western New Mexico, on the other, are somewhat in question. There seems to be valid Moenkopi in the latter area,[1] and a representative of the Shinarump and Chinle formations; but there is ground for doubt that the Wingate and Todilto(?) formations of northern

[1] N. H. Darton, "A Résumé of Arizona Geology," *Ariz. Bur. Mines Bull. 119* (1925), pp. 110, 117; "A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona," *U.S. Geol. Surv. Bull. 435* (1910), pp. 32–54; H. E. Gregory, "Geology of the Navajo Country," *U.S. Geol. Surv. Prof. Paper 93* (1917), pp. 27, 28.

Arizona are exact equivalents of the typical Wingate sandstone and Todilto limestone of eastern Arizona and northwestern New Mexico, and as to what part of the Utah sequence is equivalent to the Navajo and "McElmo" formations of northwestern New Mexico. More field study is needed before these points can be cleared up. As matters stand now, the Carmel formation of northern Arizona has been correlated through southeastern Utah with a limestone member in the middle of the La Plata sandstone of southwestern Colorado; and this limestone member in turn, with the Todilto limestone of northwestern New Mexico and eastern Arizona.[1] Should the typical La Plata prove to be equivalent to Entrada, the Arizona equivalent of the limestone would be still higher in the section. On the other hand, the Todilto(?) formation of northern Arizona has also been correlated directly with the Todilto limestone of eastern Arizona.[2] The Todilto(?) formation and the Carmel formation, separated by the Navajo sandstone, cannot both be equivalent to the Todilto limestone; and until some settlement is reached, the correlation of the other formations of the section must stand in doubt.

Eastern Arizona and northwestern New Mexico.—The correlation of the Dockum group[3] of Texas—unconformable red clays, greenish-gray sandstone, and conglomerate, irregularly bedded and containing reptilian remains, fresh-water invertebrates, and fossil wood—with the Chinle formation, accepted by Branson, appears to be well founded. That any representatives of the Glen Canyon group (Wingate, Todilto[?], and Navajo) exist in western Texas and southeastern New Mexico seems, on the other hand, very doubtful in the light of present information, but is certainly not excluded. In northeastern New Mexico the Exeter sandstone rests unconformably on Triassic red beds and was correlated by Lee[4] with the Wingate sandstone.

[1] N. H. Darton, "Red Beds in New Mexico," *U.S. Geol. Surv. Bull. 794* (in press); W. T. Lee, "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smithsonian Misc. Coll.*, Vol. LXIX (1918), No. 4, pp. 18–21; H. E. Gregory, *op. cit.*, p. 52, pl. 3.

[2] H. E. Gregory, *op. cit.*, pp. 55, 56.

[3] For description and other references, see H. W. Hoots, "Geology of a Part of Western Texas and Southeastern New Mexico," *U.S. Geol. Surv. Bull. 780* (1926), pp. 86–96.

[4] W. T. Lee, "The Morrison Shales of Southern Colorado and Northern New Mexico," *Jour. of Geol.*, Vol. X (1902), p. 45; "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smithsonian Misc. Coll.*, Vol. LXIX (1918), pp. 22–24.

Darton[1] considers it a member of the Morrison formation. Stanton[2] records 200 feet of Morrison in conformity above it, and red beds unconformably beneath it. DeFord[3] has recently recorded the presence of Exeter in western Oklahoma conformably beneath Morrison and unconformably above variegated shales and red beds. In Figure 1 the writer has placed Exeter as close to Morrison but perhaps somewhat older.

Northern Utah and southeastern Idaho.—The typical Woodside, Thaynes, and Ankareh formations[4] of northern Utah, named in ascending order, have usually been placed in the Lower Triassic, chiefly on the basis of the marine invertebrates in the Thaynes, though the Ankareh is now doubtfully classified as Triassic. The Woodside is a dark-red shale; Thaynes, an alternation of gray and blue limestones with gray and red shales and minor sandstones; and Ankareh, red sandy shales and gray sandstones. Above lie thick, light-colored Nugget sandstone and the Upper Jurassic marine Twin Creek limestone. In a paper read before the Paleontological Society of America at Cleveland in December, 1927, A. L. Mathews reported new data on these formations which may be stated as follows: In the Wasatch Mountains near Salt Lake City the Woodside shale, containing nonmarine strata below and marine Lower Triassic above, rests unconformably on the underlying Phosphoria formation (Permian) and passes up without break into the overlying beds. These are divided into two lithologic units—the lower with a large marine Lower Triassic fauna; the upper with a smaller fauna, including the genus *Daonella*, apparently of Middle Triassic age. This upper unit includes apparently much of the typical Thaynes of Boutwell, part of the lower unit not appearing at the type locality. The unfossiliferous Ankareh formation is unconformable upon the Thaynes and is placed doubtfully in the Upper Triassic. A sand-

[1] N. H. Darton, personal communication.

[2] T. W. Stanton, "The Morrison Formation and Its Relations with the Comanche Series and the Dakota Formation," *Jour. of Geol.*, Vol. XIII (1905), p. 665.

[3] R. K. DeFord, "Areal Geology of Cimarron County, Oklahoma," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XI (1927), p. 753.

[4] J. M. Boutwell, "Stratigraphy and Structure of the Park City Mining District, Utah," *Jour. of Geol.*, Vol. XV (1907), pp. 434–58; "Geology and Ore Deposits of the Park City District, Utah," *U.S. Geol. Surv. Prof. Paper 77* (1912), pp. 52–59.

stone formation that begins with a well-defined basal conglomerate and is probably equivalent to the Nugget yielded a marine fossil and tentatively is assigned to the Lower Jurassic. The Twin Creek formation rests on this sandstone with apparent conformity.

The Lower Triassic fauna of the Thaynes formation occurs also in equivalent beds in southeastern Idaho[1] and in much less extensive development in the Moenkopi formation of southern Utah.[2] The section given by Mansfield for southeastern Idaho is, in ascending order, as follows: Woodside shale, unconformable alternating olive-drab shale and brownish-gray fossiliferous marine limestone, Lower Triassic; Thaynes group, conformable, marine fossiliferous, Lower Triassic, containing three formations (Ross Fork, limestone, shale, and sandstone; Fort Hall, yellowish sandstones below, olive-drab shales above; Portneuf, olive-drab limestones with some red sandstone and shale); Timothy sandstone, unconformable yellowish, locally reddish, sandstone containing local conglomeratic beds and obscure plant remains, doubtfully Lower Triassic; three doubtfully Triassic formations, unconformable Higham grit, Deadman limestone, and Wood shale, the latter red and gypsiferous; possibly unconformable Nugget sandstone, Jurassic; Twin Creek limestone, unconformable, fossiliferous marine, Upper Jurassic and possibly in part Middle Jurassic; Preuss sandstone, unconformable, barren; Stump sandstone, conformable, fossiliferous marine, Upper Jurassic; Gannett group, unconformable, nonmarine, possibly Lower Cretaceous.

Unless the Timothy sandstone with its plant remains and its conglomerates represents the interval of the Chinle and the Shinarump, there is no clear evidence of the presence in northern Utah and southeastern Idaho of the widespread Upper Triassic deposits. It seems to the writer that the best present interpretation is to correlate the Timothy sandstone with the Shinarump and Chinle and assign it to the Upper Triassic, and to correlate the Higham, Dead-

[1] G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U.S. Geol. Surv. Prof. Paper 152* (1927), pp. 84–96, 373–76.

[2] J. B. Reeside, Jr., and Harvey Bassler, "Stratigraphic Sections Southwestern Utah and Northwestern Arizona," *U.S. Geol. Surv. Prof. Paper 129* (1922), pp. 59–62, 67–68.

man, and Wood with the Ankareh and consider them as closely associated with the Nugget sandstone and probably of Jurassic age. There has been some confusion in the use of the name Ankareh, as demonstrated by Mansfield,[1] and some difference of opinion as to its relations with adjacent formations, though the most recent data seem to warrant a reversion to the original concept of Ankareh as closely related to Nugget. The Nugget sandstone itself approaches in character very closely the Navajo and Entrada sandstones of southern Utah and the basal sandstone of the Sundance of Wyoming.[2]

Northwestern Colorado.—In the eastern Uinta Mountains in northwestern Colorado[3] the section contains in ascending order: undifferentiated Woodside and Thaynes(?)[4] formations, apparently conformable red, locally gray and drab, shale, minor sandstone and limestone, unfossiliferous, Lower Triassic; Ankareh(?)[4] formation, unconformable grit, sandstone, and red and gray sandy shale; Nugget sandstone, conformable, thick, white and gray, cross-bedded, Jurassic; Twin Creek limestone, conformable, fossiliferous marine limestone and shale, Upper Jurassic; Morrison formation, doubtfully Cretaceous. The evidence of such tracing as is possible, stratigraphic position, structural relations, and lithology makes the continuity of the Woodside and Thaynes(?) of the eastern Uintas with the Woodside and Thaynes of the western Uintas very nearly certain, though a paleontologic tie is not available, and division into units in the east does not seem feasible. The Ankareh(?) formation of the eastern Uintas seems to correspond best to the Ankareh formation of the western Uintas and is most logically viewed as introductory to the

[1] *Op. cit.*, p. 82.

[2] W. T. Lee, "Correlation of Geologic Formations between East-central Colorado, Central Wyoming, and Southern Montana," *U.S. Geol. Surv. Paper 149* (1927), pp. 15–17.

[3] J. D. Sears, "Geology and Oil and Gas Prospects of Part of Moffat County, Colorado, and Southern Sweetwater County, Wyoming," *U.S. Geol. Surv. Bull. 751* (1924), pp. 277, 280, 284; J. B. Reeside, Jr., "Notes on the Geology of Green River Valley between Green River, Wyoming, and Green River, Utah," *U.S. Geol. Surv. Prof. Paper 132* (1923), pp. 38, 40, 43, 45, 48; A. R. Schultz, "Oil Possibilities in and around Baster Basin, in the Rock Springs Uplift, Sweetwater County, Wyoming," *U.S. Geol. Surv. Bull. 702* (1920), tables opp. pp. 24, 36.

[4] Branson, in quoting Sears, omits the queries.

Nugget. The Nugget sandstone itself, on its lithology and structural relations, seems best correlated with some part of the Navajo-Entrada sequence and, as Lee suggests,[1] with the basal sandstone of the Sundance formation of Wyoming, though again a paleontologic tie is not available.

Wyoming.—The Chugwater formation at its type locality in southeast Wyoming by definition[2] included all of the red beds in the section between the Pennsylvanian Tensleep sandstone and the Jurassic Sundance formation. In extending the use of the name, a similar interpretation was often put upon it, to the effect that there were lumped together various red beds—from those demonstrably Permian to those demonstrably Upper Jurassic in age—ignoring various differences in lithology, unconformities, fossil content, etc. Branson has accepted this concept, unfortunately with considerable confusion to the reader, for there is a general lack of specification, when the term "Chugwater" is used, as to what part of the assemblage of different sorts of rock is meant. In several areas the Permian part of the "Red Beds" has been separated from the Chugwater and given distinctive formation names, and the Chugwater formation has been further restricted by the removal of the Jelm ("Popo Agie") formation at the top. Lee[3] has recently discussed these and other subdivisions. Brainerd and Keyte[4] have also called attention to the desirability of separation of the upper part. On the basis of personal observations and the printed record it seems to the writer most logical to divide the "Red Beds" into four divisions: (1) a basal unit of interbedded Permian red beds and minor limestones, including the Forelle limestone and Satanka shale and passing westward into the Phosphoria formation and northward into the Embar formation; (2) an apparently conformable, though probably unconformable, unit of red beds with minor limestone members, Lower

[1] *U.S. Geol. Surv. Prof. Paper 149* (1927), p. 16.

[2] N. H. Darton, "Comparison of the Stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range," *Bull. Geol. Soc. Amer.*, Vol. XV (1904), p. 397.

[3] W. T. Lee, *U.S. Geol. Surv. Prof. Paper 149* (1927), pp. 10–16.

[4] A. E. Brainerd and I. A. Keyte, "Some Problems of the Chugwater-Sundance Contact in the Bighorn District of Wyoming," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XI (1927), pp. 747–52.

Triassic and possibly in small part Middle Triassic, the basal part passing westward into the Dinwoody formation; (3) the unconformable nonmarine Jelm ("Popo Agie beds"), absent at some localities; (4) the unconformable basal sandstone of the Sundance and the overlying red beds of the Sundance.

The writer believes with Lee[1] that the Jelm and "Popo Agie beds" are essentially the same; that they are unconformable on the underlying beds, the unconformity representing much of the Middle Triassic and possibly part of Upper Triassic time; that the differences in the scanty vertebrate faunas are more likely due to the accidents of preservation and of collecting than to difference in age; and that the structural relations, stratigraphic position, and lithology must be considered of superior weight. It seems to the writer that Branson is inconsistent in discarding the evidence of the vertebrates,[2] while using the differences in the recorded vertebrate faunas of the "Popo Agie beds" and the Jelm formation to support the interpretation of difference in age.[3]

The writer believes that the name Chugwater would best be restricted to the part of the red beds between the Permian and the base of the Jelm ("Popo Agie"), wherever these limits can be drawn. This is in accord with the present practice of the U.S. Geological Survey, which is to place the top of the Chugwater at the base of the Jelm ("Popo Agie"), where that unit is recognized, and excludes from the Chugwater the Dinwoody, Embar, Phosphoria, Forelle, and Satanka formations wherever any of these are recognized. In some areas, notably the east side of the Bighorn Mountains, where the foregoing units have not been differentiated, Chugwater is still used to include rocks of Permian age. The red beds of Upper Jurassic age have always been excluded from the Chugwater where recognized as such by their invertebrate fossils. The upper boundary of the Chugwater, as thus defined, is at many places not far above the top of the Alcova limestone. It seems at least highly probable that the marine Dinwoody formation grades eastward into the lower Chugwater (as thus restricted) and this feature, together with the occurrence of the marine Alcova limestone near the top and the physical character-

[1] W. T. Lee, *U.S. Geol. Surv. Prof. Paper 149* (1927), p. 14.

[2] E. B. Branson, *op. cit.*, p. 616. [3] *Ibid.*, p. 615.

istics of the intermediate sediments, make plausible the assumption of marine origin for this part of the red-bed sequence. The so-called "upper Chugwater red beds" above the "Popo Agie beds" near Lander, Wyoming, cited by Branson as of marine origin and therefore indicating a position for the "Popo Agie beds" below that of the Jelm formation[1] are in the writer's opinion merely the widespread lower Sundance (Upper Jurassic). These beds do contain at places marine fossils, specifically in a zone between the basal sandstone and the overlying red beds, and the red beds themselves have bedding and other features similar to those of the Chugwater (restricted); but the fossils are Upper Jurassic and therefore the beds have little bearing on the relations of "Popo Agie" and Jelm to the Chugwater.

Black Hills and eastern Colorado.—Branson interprets the Spearfish formation of the Black Hills to follow the Lykins formation of the foothills of the Front Range of Colorado directly in time. The Lykins formation has been described most recently by Henderson[2] and Lee,[3] and the Chugwater of the nearby area in Wyoming by Lee and Darton and Siebenthal;[4] and it seems to the writer that the Lykins contains the restricted Chugwater and also some Permian beds at the base. Lee thought he saw a thin representative of the Jelm formation at some places—a suggestion to which earlier reports of Upper Triassic vertebrates in Colorado lend credibility. The Spearfish formation and underlying Minnekahta limestone[5] are not so easily assigned. The Spearfish seems to be of the same type of red beds as the Chugwater (restricted) and would on that ground be essentially Lower Triassic. The Minnekahta limestone occupies a place in the section that appears to correspond to that of the Forelle limestone (Permian) of southern Wyoming, though the fossils of the

[1] *Ibid.*, pp. 614, 617.

[2] Junius Henderson, "The Foothills Formations of North-Central Colorado," *Colo. Geol. Surv. Bull. 19* (1920), pp. 76–78.

[3] W. T. Lee, *U.S. Geol. Surv. Prof. Paper 149* (1927), p. 10.

[4] N. H. Darton, Eliot Blackwelder, and C. E. Siebenthal, "Laramie-Sherman Folio," *U.S. Geol. Surv. Geol. Atlas*, Folio 173 (1910), pp. 7–8. Branson (p. 611) credits this folio to Blackwelder, who wrote only the parts concerning the pre-Cambrian.

[5] N. H. Darton and Sidney Paige, "Central Black Hills Folio," *U.S. Geol. Surv. Geol. Atlas*, Folio 219 (1925), pp. 9, 10.

Minnekahta are more like those of the Alcova limestone.[1] All three limestones are curious, minutely-banded and colored "ribbon" limestones. If the Minnekahta is equivalent to the Alcova, the Spearfish is equivalent to Jelm and of Upper Triassic age. The eastward overlap of Upper Triassic over Lower in Utah and Colorado would offer a parallel for such a situation. On the other hand, there is very little warrant for a correlation of Spearfish and Jelm on faunal or physical grounds, and very little warrant in general for the supposition that any Upper Triassic beds exist in the Black Hills region. Nearly everything known about Spearfish and much of the Lykins links them both with the Chugwater (restricted) and seems to the writer directly against the interpretation that Lykins precedes Spearfish in time.

SEPARATION OF UPPER AND LOWER "RED BEDS"

Concerning the separation of the lower from the upper "Red Beds" in the Rocky Mountain region, the foregoing discussion of local sections and correlations indicates that several divisions in the Mesozoic part of the sequence are both possible and desirable. In brief repetition these divisions are: (1) A widespread unit, in the main Lower Triassic, but at one locality reported as extending somewhat into the Middle Triassic and possibly also at other localities where evidence is now lacking. It is separated from the preceding Permian beds, in part red beds, by a hiatus. Westward it includes a progressively increasing proportion of fossiliferous marine beds, and eastward, though unfossiliferous, at least indicates deposition in a large body of water. (2) An Upper Triassic unit, widespread in the south but possibly sporadic in occurrence in the north. It is separated from the preceding beds by a hiatus which corresponds to much of Middle and perhaps part of Upper Triassic time. It bears everywhere evidence of fluviatile origin. (3) A Jurassic unit representing part of Upper Jurassic time and an undetermined part of older Jurassic time, and separated from the preceding beds by a hiatus. This unit begins with large sandstones, which have yielded a few non-marine fossils and are in part subaerial in origin, and then passes into marine deposits, in part red, which have yielded Upper Jurassic fossils.

[1] G. H. Girty, personal communication.

EOLIAN DEPOSITS

Regarding the question of the formation of eolian deposits during the time interval covered by the term "red beds" in its larger sense —from Permian to Upper Jurassic and including such formations as the basal sandstone of the Sundance, the Nugget sandstone, the Glen Canyon Group, the La Plata sandstone, etc.—Branson decides that there were no eolian deposits of any importance whatever, and that the "Red Beds" are marine deposits and subaerial delta materials. He says of the large, cross-bedded, chiefly non-red sandstones:

> The La Plata, Navajo, and Wingate have none of the qualities of subaerial deposits. They are in the main thick bedded, and some of the beds are remarkably thick. The thick beds are usually cross-bedded, in part foreset beds of deltas. The beds do not change abruptly in composition. One may trace them for many miles without being able to detect any change in texture or thickness of beds. Ripple marks are common. No land fossils have been found save a so-called dinosaur footprint in the Todilto, which lies between the Wingate and Navajo and seems to be of the same origin.[1]

At another place:

> Perhaps the question of the possible eolian origin of considerable parts of the Wingate, Navajo, La Plata, and Chugwater should not be dismissed as summarily as by Twenhofel. . . . . The writer is in agreement with Twenhofel in considering such an origin as clearly impossible. Winds do not create widespread beds of even thickness; wind deposits are not ripple marked on extensive surfaces; extensive wind deposits vary greatly in texture from coarse, well-rounded almost pure quartz sand, on the one hand, to heterogeneous loesslike deposits, to fine silt deposits. It has been rather generally assumed that wind deposits should have well-rounded grains and be uniform in texture and composition. This is true of the fairly coarse wind-blown sands, but where the modal grains are less than $\frac{1}{4}$ mm. in size the materials are highly heterogeneous and the grains are mainly angular. . . . . In an area of deposition as large as that covered by the Wingate, Navajo, or any of the red bed sands, the fine dune sand, loess, and adobe should be much larger in amount than the coarse dune sand, but the sands of all these formations are remarkably well sorted.[2]

The writer would agree with Branson that the red beds proper, i.e., excluding the large sandstone formations, give little evidence of eolian origin; further, that parts of the large, cross-bedded sandstones, in part red but chiefly non-red, are by most of our ordinary

[1] *Ibid.*, p. 627. [2] *Ibid.*, pp. 629, 630.

criteria water-laid. On the other hand, to say on the basis of present data that eolian origin or, in larger terms, subaerial origin is "clearly impossible" for a considerable part of the large sandstone formations, does not appear to be justified. It is premature to settle so important and complex a question in this out-of-hand fashion and on purely theoretical grounds. When much more first-hand information is available than anyone has yet given evidence of possessing, we may hope for a definite answer regarding the origin of this imposing part of the Mesozoic sequence. In the meanwhile a reserved judgment would seem to be the safer and wiser attitude. The gross characters of the sandstones in question have been given by description and photograph in many papers and it seems of little service to repeat them here. Suffice it to say that Branson's picture of them does not seem to the writer entirely accurate. There are certain planes that can be followed over large areas, it is true, but they are few and the thicknesses of rock between, in which very large-scale tangential cross-bedding is conspicuous, are large. In the Navajo particularly is this true. Here and there in the Navajo are "pans" of sandy limestone, a small fraction of a mile in diameter and a few feet thick, often containing thin sheets which were cracked and curled by drying and then covered by sand, the sand now filling the cracks around the sharp-edged and "unwilted" curls. At at least one locality the Navajo contains perfectly typical dreikanter. The writer has not seen extensive, flat, ripple-marked surfaces anywhere in the large sandstone formations (except possibly in some thin water-laid parts and in the Todilto(?), where also occur shells of *Unio* and vegetable débris)—in fact, ripple marks are unusually rare—and the writer suspects in Branson's statements a confusion with some of the possibly marine red beds. Footprints have been observed in other parts of the sequence in addition to the Todilto(?). In short, the mass of evidence seems against the theory of marine origin set forth by Branson, and there is a considerable amount in favor of subaerial and even of eolian origin. The writer is led to wonder whether the characters of extensive wind deposits, as given in the second quotation above, are sufficiently well founded to fix the criteria by which we must judge all deposits of all geologic time. The supposed absence of present-day eolian deposits of extent and thickness comparable to those of

these ancient sandstones is an unconvincing argument, and the theoretical improbability of the wind's being able to build such formations does not seem to the writer to preclude such an origin. The deposits themselves seem to the present writer to have on a grand scale the characteristics of present-day small-scale eolian formations. At any rate, a more or less perfunctory dismissal of the question serves no useful purpose.

PALEOGEOGRAPHY

Branson's paleogeographic map of Upper Triassic time (his Fig. 2) would be difficult to defend. The beds accepted as definitely Upper Triassic in the area shown as sea from eastern Nevada eastward are all nonmarine, probably fluviatile deposits. The marine and probably marine red beds known are in greater part Lower Triassic, in lesser part Upper Jurassic, but none are Upper Triassic. The great river system is based on the interpretation of Dockum, Chinle, etc., as delta materials interfingering with the marine deposits—an untrue assumption, for there is no known interfingering, but on the contrary widespread sharp separation. In western Nevada and in the Pacific states, marine Upper Triassic occurs,[1] but there is no known connection with the non-marine Upper Triassic beds of the region farther inland.

CONCLUSIONS

In summary, the present writer would agree with Branson that part of the sequence of red-bed formations in the Rocky Mountain region may be marine and that part is certainly non-marine. He disagrees with much of Branson's correlation table, particularly the conclusion that there is no basis for subdivision of the red beds, and finds three widespread units present, in age essentially Lower Triassic, Upper Triassic, and Jurassic. The Permian red beds constitute a fourth unit. He believes that the lower part of the Jurassic unit contains important eolian deposits, and that the paleographic map of Upper Triassic time is invalid because based on an erroneous interpretation of the stratigraphy.

[1] J. P. Smith, "Upper Triassic Marine Invertebrate Faunas of North America," *U.S. Geol. Surv. Prof. Paper 141* (1927), pp. 2–13.

"TRIASSIC-JURASSIC 'RED BEDS' OF THE ROCKY MOUNTAIN REGION": A REPLY

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ABSTRACT

Misinterpretations of several of Branson's statements are pointed out. The conclusion that no large parts of the red beds are eolian in origin is reiterated, and additional evidences are given. The uncertainty of red-bed correlation is emphasized again, and Dr. Reeside's correlations are shown to be based on extremely insecure data. The relationships of the Popo Agie beds are stated to give no basis for making them a positive division-place in the Chugwater. Present information about red-bed vertebrate fossils is considered insufficient for correlations and age determinations.

GENERAL STATEMENT

In the paper "Triassic-Jurassic 'Red Beds' of the Rocky Mountain Region" Dr. Reeside discusses several objections to certain conceptions set forth by Branson in a previous article under the same title. The discussion warrants a rather long reply in order to correct some of Dr. Reeside's misinterpretations, to meet some objections with more thorough explanations, to discuss some differences of opinion, and to point out some errors on which conclusions are based.

MISINTERPRETATIONS

Reeside states his first point of disagreement with the writer as follows: "The conclusion that there exists no basis for subdivision of the beds is not accepted." In the writer's abstract he says, "No worth-while basis for the separation of the upper red beds from the lower was found." This should have read, "for the separation of the upper Chugwater from the lower." In the body of the paper the red beds are subdivided in various ways.

Reeside says: "It seems to the writer that Branson is inconsistent in discarding the evidence of the vertebrates while using the differences in the recorded vertebrate faunas of the 'Popo Agie beds' and the Jelm formation to support the interpretation of difference in age" (p. 58). "The so-called 'upper Chugwater red beds' above the 'Popo Agie beds' near Lander, cited by Branson as of marine origin and *therefore indicating a position for the 'Popo Agie beds' below*

that of the Jelm formation" (p. 59, italics by Branson). Branson uses no such reasoning, but says that "the southern place [Jelm] may have been older or younger" than the Popo Agie. As both were deposited in short intervals of subaerial and near shore deposition, such as existed at places throughout Chugwater time, contemporaneity would be much less likely than difference in age.

Reeside says: "The conclusion that no eolian deposits are present likewise is not accepted, and the interpretation of important parts of the Jurassic unit as eolian is advocated." Branson says[1] that no appreciable part, or no considerable parts, are eolian. Reeside gives a curious twist to his discussion of this phase of the subject. Branson discussed it strictly on the basis of eolian deposition, but Reeside says, "to say on the basis of present data that eolian origin, or, in other terms, *subaerial origin* [Branson's italics] is 'clearly impossible' for a considerable part of the large sandstone formations, does not appear to be justified" (p. 62). The objections to Branson's conclusions concerning wind-blown origin are, perhaps, clear enough without reverting to the confusion in terms, though it is not clear whether Branson's criteria are accepted by Reeside.

EOLIAN ORIGIN OF SOME PARTS OF THE RED BEDS

Branson said that it is unlikely that well-sorted sand beds of wide extent would originate as eolian, as the wind sorts only the coarser sands and alternates these with poorly sorted loess-like deposits. There might be a few miles of dunes, but on the leeward side there would be the loess or adobe type, just as such types are found today on the leeward side of the well-sorted materials. The writer has not examined the desert deposits of Asia and Africa, but he has seen most of those of North America, and they do not indicate that the well-sorted materials could make up beds of wide extent.

In order to meet the question of origin without possibility of quibble, take a phase of the Navajo, of which Reeside says: "The deposits themselves seem to the present writer to have on a grand scale the characteristics of present-day small-scale eolian formations" (p. 63). A massive member of the Navajo, upward of 100 feet

[1] E. B. Branson, "Tr sic-Jurassic 'Red Beds' of the Rocky Mountain Region," *Journal of Geology*, Vol. XXXV (1927), pp. 629–30.

thick, shows no good bedding in the entire mass, though cross bedding is common. The member has neither the thin beds nor the ripple marks that Branson used in deciding that some of the other members were subaqueous in origin. The member extends over several thousand square miles, has top and bottom bounded by even planes, and is made up of well-sorted sand. The origin is a puzzling problem, but more so if considered eolian than subaqueous. If the bottom were wind-blown and if the underlying rocks, which are also sandstone of the same type, but better bedded, were subject to the action of the wind, the even lower surface could not remain. But assuming that some other agent smoothed out the sands and allowed the dunes to be piled up over an even surface, the problem of the plane top remains. Where the writer has observed the top of the thick member, it is as regular as an ordinary marine sandstone bed. If of eolian origin, the sand must have been in dunes, with great surface irregularities, unless we are to suppose that the winds in the past piled up sand in different ways than today. If a sea or lake spread over the dune region, an even top could be produced and part of the member remain eolian, but such a body of water is excluded by Reeside's hypothesis. Streams could not have produced the even top unless the area were nearly at base level, and then the sorting would have been entirely different from that which is present, and strikingly irregular phases would appear. As several such members are present, the process of leveling top and bottom must have been repeated several times.

According to the writer's observations, parts of the Wingate, Navajo, and La Plata, and some parts of the Chugwater, are in very thick members showing little bedding; but the members have even tops and bottoms. One thick member is succeeded by another thick member or by thin members. Reeside says: "There are certain planes that can be followed over large areas, it is true, but they are few and the thicknesses of rock between, in which very large-scale tangential cross bedding is conspicuous, are large" (p. 62). All planes must have been made by some agent other than the wind, and bodies of water seem to be the only agent capable of producing them.

Reeside mentions several evidences of subaerial deposits in the Navajo. Branson calls attention to subaerial deposits in many

places and says that some of the upper Chugwater may be eolian but that it seems better explained on some other basis. For the benefit of those unfamiliar with the formations in the field, Reeside should emphasize the scarcity of footprints rather than mention them as evidence of subaerial origin in the formations under discussion. The writer has never seen a footprint in any of the Triassic or Jurassic red beds save one series from the Popo Agie beds, and it is his impression that they have been found only in a very few places. The presence of dreikanter in the Navajo is remarkable but not significant. The writer's only experience with dreikanter in the field has been on high wind-swept plateaus where there was little loose sand.

Some local pans produced by the drying up of shallow lakes, a few occurrences of footprints, absence of ripple marks on flat surfaces, and tangential bedding of thick members between certain planes that can be followed over large areas constitute Reeside's "mass of evidence that seems against the theory of marine origin" (p. 62).

The writer pictures the red beds as originating in shallow seas of wide extent. In some places at some times the seas were filled and the wind worked over the loose sands, rarely creating a bed that retained some of its wind-blown characters when the seas readvanced. There may have been places where wind action was the last phase of red-bed formation, but strictly wind-formed members are rare and hard to identify, while successive wind-formed members have not come to the writer's attention. At all times shore phases of combined subaerial and subaqueous origin were forming, but in most cases they were of small extent, and only rarely have they been differentiated from the other red beds.

The writer is fully agreed that the time has not come to draw positive conclusions concerning the origin of all of the red beds; but we may apply our criteria, in as far as we have such, to the parts that we study, and eliminate some of the conflicting opinions which we now hold. One of our drawbacks is that in no place are we able to present all of our evidences. The writer in his paper intended to emphasize two things: the evidences of marine origin of the beds, and the uselessness of the present collections of vertebrate fossils in making correlations. That he did not confine himself to those points was accidental rather than intentional.

CORRELATIONS

"Disagreement is expressed with much of Branson's correlation table and a substitute is offered." Branson made no claims for his correlation table, but, on the other hand, emphasized the difficulties of making correlations. As he knew that Lee's paper on the reclassification and correlation of the formations in the region under discussion was in press, he did not consider it worth while to take up a discussion of the correlation of all of the formations involved. Reeside's correlations are based almost wholly on lithology and represent opinion rather than anything stronger. His extensive investigations of the red beds have given him a familiarity with them possessed by few investigators, though, judging from his publications, most of his work has been on formations other than the red beds. For almost every one of his correlations a substitute could be suggested on substantial grounds; but a call for proof would be met, as in his paper, by "seems best correlated" or "seems to the writer."

Reeside declines to accept the statement of the writer and others who have investigated the Popo Agie beds that they are not at the top of the Chugwater in central Wyoming. "And the Chugwater formation has been further restricted by the removal of the Jelm (Popo Agie[1]) formation from the top" (p. 57).

The writer has spent about ten months, distributed through seven years, in investigating the Popo Agie member. He has examined practically every outcrop along the east slope of the Wind River Mountains and worked over the entire exposures which extend for about 100 miles, from 25 miles southeast of Lander to 75 miles northwest. These mountains are paralleled by a series of anticlines with crests a few miles east of the main range, and the writer has worked over every outcrop in the anticlines. He has also extended his investigations in all directions from the main outcrops to beyond the

[1] Popo Agie preceded Jelm in the literature by twelve years, being proposed by Williston (S. W. Williston, "Notice of Some New Reptiles from the Upper Trias of Wyoming," *Jour. of Geol.*, Vol. XII, p. 688) in 1904. Williston did not give an adequate description, but in 1915 Branson (E. B. Branson, "Origin of the Red Beds of Western Wyoming," *Bull. Geol. Soc. Amer.*, Vol. XXVI, pp. 220–21) described the member more fully. It was not until two years later that Knight (S. H. Knight, "Age and Origin of the Red Beds of Southeastern Wyoming," *ibid.*, Vol. XXVIII [1917], p. 168) proposed Jelm, and it has never been described. The Popo Agie has been recognized over wide areas, and a map of its extent is given in a forthcoming paper by Branson and Mehl.

limits of the Popo Agie beds. His views on the origin of the Popo Agie beds are expressed in other papers, and no one has disagreed with them.

The unconformity at the base of the Popo Agie in the Wind River region is no more pronounced than one would expect where subaerial beds are built out over marine beds. The unconformity at the top is negligible, non-detectable in most places, and no greater than one would expect from reinvasion of seas after the deposition of topset beds of deltas and other subaerial deposits. The best development of the member is on the east slope of the Wind River Mountains, where it attains a thickness of 100 feet in some places. Twenty-four miles east of the northernmost Wind River exposures, near Dubois, there are good exposures on the south side of the Owl Creek Mountains, and the lithology is indistinguishable from that in the Wind Rivers. On the north side of the Owl Creeks, near the old Embar Ranch, about 25 miles from the locality mentioned on the south side, the Popo Agie beds are discontinuous, 2 or 3 feet thick at the most, and grade into the ordinary red-bed lithology with no unconformity either above or below. The member may be identified by its sparse bone content and in a few places by its lithology.

At Thermopolis, 30 miles east of Embar, no Popo Agie member has been observed. On the west slope of the Big Horn Mountains, as well as on the east slope, the writer has searched for Popo Agie beds over wide areas but has found none; and he has found no evidence of unconformity between the lower and upper parts of the red beds.

Reeside says, "The so-called 'upper Chugwater red beds' above the 'Popo Agie beds' near Lander, Wyoming, cited by Branson as of marine origin and therefore indicating a position for the Popo Agie beds below that of the Jelm formation, are in the writer's opinion merely the widespread lower Sundance upper Jurassic" (p. 59). The misstatement of Branson's conclusions is discussed in another paragraph. The conclusion that the upper red beds are merely the widespread lower Sundance has little foundation and seems to be based, in part, on the observations listed in the following quotation: "These beds (upper Chugwater, non-restricted) do contain at places marine fossils, specifically in a zone between the basal sandstone and the

overlying red beds . . . . but the fossils are upper Jurassic. . . . ." As discussed by Brainerd and Keyte,[1] and as has long been known to several investigators, there is a meager fauna in a limestone member near the top of the Chugwater. This had not been identified positively as Jurassic before Brainerd and Keyte's paper, and the fossils are very scanty on which to base a positive identification of Upper Jurassic. Five miles south of Lander, the Chugwater section is 1,400–1,600 feet thick, the Popo Agie member is 800–900 feet from the bottom, and the thin limestone which bears the invertebrate fossils is 100 feet below the lowest fossiliferous Sundance. The fossils in the limestone are poorly preserved, and no species seems to be related to the species in the Sundance. There is no break of importance above the Popo Agie, and there is no detectable break below the fossil-bearing limestone near the top. This condition is similar to that found wherever the writer has examined the Chugwater, and Brainerd and Keyte emphasize it. Reeside accepts the Popo Agie beds as definitely Upper Triassic, and calls all of the Chugwater below the Popo Agie Lower Triassic, although conceding that some of it may be Middle Triassic. "The Spearfish seems to be of the same type of red beds as the Chugwater (restricted) and would on the ground be essentially Lower Triassic." He makes the contact between the Popo Agie beds and the red beds below, the top of the Lower Triassic. The writer considers that there is no basis for drawing such a line and that Upper and Middle Triassic may extend well down in the lower Chugwater. The question remains open, but the drawing of a definite line with present data merely misleads those not familiar with the formations. An error of inference is that the unconformity at the base of the Popo Agie beds represents all of Middle Triassic.

Above the Popo Agie, Reeside assigns the red beds to the Sundance. This, too, is without warrant and can only lead to misunderstanding of the problems involved. Where the Popo Agie beds are absent, there is no unconformity between the upper Chugwater and the lower; and Reeside's classification would place Upper Jurassic red beds on Lower Triassic red beds where there is perfect gradation between the two. An error of inference is in supposing that an un-

[1] *Bull. Amer. Assoc. Pet. Geologists*, Vol. XI, pp. 747–52.

conformity at the top of the Popo Agie represents part of Upper Triassic and a goodly amount of Jurassic. The writer suggested that the Popo Agie beds would make a convenient place to draw the line where they are present, but there is no evidence that the beds above belong to the Sundance; and if they are to be separated from the underlying red beds, they should be given a different name and should be designated as Triassic or Jurassic. There is a well-marked unconformity between the Sundance proper and the top of the red beds, 600 feet above the Popo Agie beds, in the Wind River Mountain region.

As an example of the precision of Reeside's correlation, consider the discussion of the Spearfish and Minnekahta. He says that these formations "are not so easily assigned" as the Lykins, which is disposed of by saying that it "contains the restricted Chugwater [with representatives of the Jelm] and also some Permian beds at the base." Whenever a subaerial near-shore phase containing some bone fragments is found, it is referred to the Jelm and supposed to be of the same age as the Jelm of southern Colorado. While seeming to accept Branson's outline of the origin of the Chugwater (restricted) and the Jelm and Popo Agie beds, he continues to assume that near-shore and subaerial phases, where found, are of the same age as near-shore phases found at other places.

The Lykins and the Jelm are easily disposed of by Reeside, but to the writer the disposition seems to have little foundation.

"The Spearfish seems to be of the same type as the Chugwater (restricted) and would on that ground be essentially Lower Triassic." Reeside places Chugwater (restricted) in the Lower Triassic on false assumptions; and now the Spearfish goes with it on the basis of lithology, though the lithology above the "restricted" Chugwater is indistinguishable from that below on the east slope of the Wind River Mountains, both sides of the Owl Creeks, and both sides of the Big Horns. No line can be drawn except where the Popo Agie member is present. The lower Chugwater on the west slope of the Big Horn Mountains could not be correlated definitely with the lower Chugwater of the Wind River Mountains 80 miles away if the upper Chugwater were not there to indicate that the part below is lower Chugwater. Lithology is quite different in the places 80

miles apart, but Reeside ventures a rather close correlation of the Spearfish in the Black Hills, 150 miles east of the outcrops on the western base of the Big Horns. The writer would say that the Spearfish may be upper Chugwater, lower Chugwater, or middle Chugwater, but that it appears to represent much the same time and conditions as the entire Chugwater of the Wind River Mountains which thins gradually eastward. No attempt at exact correlation should be made on such data.

On the same page Reeside shifts the Spearfish to Upper Triassic on the basis of a few fossils. "If the Minnekahta is equivalent to the Alcova, the Spearfish is equivalent to Jelm and of Upper Triassic age" (p. 60). A few fossils might shift most of the formations in Reeside's list almost as far as the Spearfish is shifted. The paleontological data for the shifting are taken from Lee, who concludes:

> Although recognized as inadequate for final determination of age, these fossils indicate that the limestone is of marine origin and probably Triassic. As the only marine Triassic rocks anywhere near central Wyoming are recognized as Lower Triassic, it is probable that the Alcova limestone also should be classed as Lower Triassic.[1]

Reeside's correlation table represents his opinions, and he probably would be ready to shift his formations on the basis of very slight paleontological evidence. The writer's table represents opinions, and he recognizes his correlations as no better than the data on which they are based. The geologist who has not worked on the red beds should understand that essentially every formation above the sparsely fossiliferous Moenkopi, which has been referred to the Permian in the past on the basis of its fossils, and the Woodside and Thaynes, is correlated on the basis of lithology and of attempted tracing of beds, and that the latter has not been thoroughly done anywhere and is impossible in most places. Reeside expresses uncertainty about the correlation of almost every formation.

It seems unnecessary to take up the individual correlations made by Reeside, but some others may serve to emphasize the points made in the last paragraph.

The Shinarump conglomerate, Chinle formation, Wingate sandstone, and Todilto(?) formation seem to occupy the interval of the Dolores formation and

[1] W. T. Lee, "Correlation of Geologic Formations between East-Central Colorado, Central Wyoming, and Southern Montana," *U.S. Geol. Surv., Prof. Paper 149* (1927).

were so identified by Cross, though some difference of opinion now exists as to whether Wingate and Todilto(?) extend as far eastward as the typical area of the Dolores, and it may be found equivalent then to Shinarump and Chinle only [p. 51].

This is a plain statement of the impossibility of definite correlation of the top of the Dolores. It may be of Jurassic age or of Triassic.

Reeside says, "The base of the Shinarump, the base of the Chinle where Shinarump is not recognized, and the base of the Dolores mark a widespread unconformity, the significance of which has been completely missed by Branson" (p. 52). In northwestern and western New Mexico and in northeastern, eastern, and central Arizona, where the writer has observed the contacts mentioned in the foregoing sentence, he has seen no positive evidence of unconformity. An angular unconformity is exposed along the Little Colorado River a few miles from its mouth. Assuming that the writer has overlooked an unconformity that is everywhere present between the Chinle and Moenkopi and the Shinarump and Moenkopi, the justification for assuming that this represents practically all of Middle Triassic is not apparent. The Moenkopi faunas are sparse and do not extend to the top of the formation; the Chinle above the unconformity has been called Upper Triassic and Middle Triassic on the basis of its vertebrate fossils.

The writer does not accept Reeside's conclusions about the absence of "perhaps most of the Middle Triassic" (p. 52) in Arizona, New Mexico, Colorado, and Utah in the region where the four states corner, any more than he accepts the absence of Middle Triassic in the Chugwater. He considers both conclusions to be worthy of consideration as from one who has investigated the formations extensively, but as merely opinions, with the weight of evidence strongly against the latter, and with little evidence in support of the former.

Reeside's definite rejection of Branson's generalized correlations are always accompanied by a "seemingly" or other qualifying word. Anyone who has worked extensively on the red beds will wonder how Reeside can reject correlations as a whole so positively while he qualifies all of his own correlations, and, finally, makes sweeping conclusions based on his correlations.

Branson emphasized the uselessness of vertebrate fossils for correlation purposes considering our present knowledge of them, and two

forth-coming papers by Branson and Mehl discuss this at some length. Reeside seems to reject Branson's conclusion, but he also rejects von Huene's conclusions,[1] as he considers that there is little or no Middle Triassic in the red-bed series; while von Huene places most of the vertebrate bearing beds in Middle Triassic. This seems to be a selection and rejection of data quite without justification. The writer did not reject von Huene's reference of many phases of the red beds to Middle Triassic, but said that the vertebrate remains do not furnish conclusive evidence for correlation and, it may be added, for age. The red-bed vertebrates closely resemble the Upper Triassic vertebrates of Europe; but when as close a student of European Triassic vertebrates as von Huene refers most of the American forms to Middle Triassic, the opinion should not be rejected by American geologists without studying the European forms. The writer emphasizes again the point that vertebrate forms give no basis for correlation among Rocky Mountain red beds. He finds no basis for determining whether the Popo Agie beds are older or younger than the Jelm, older or younger than the lowest fossiliferous beds of the Dolores, older or younger than the highest fossiliferous beds of the Dolores, or older or younger than any fossiliferous member of the Chinle. Even had the horizons of the fossiliferous members of the Chinle and Dolores been carefully recorded, which they have not, the remains are too sparse, represent too few species and too small an amount of collecting, to be of use in correlations.

Reeside says that Branson's paleogeographic map "would be difficult to defend" (p. 63). If one accepted all of Reeside's conclusions, the map could have no defense; but many of his correlations are mere suppositions, and he dogmatically calls certain formations eolian or subaerial in origin that Branson considers marine.

Reeside keeps the Upper Triassic sea out of Wyoming, Colorado, and Utah by merely referring the strata that Branson considers Upper Triassic to the Jurassic or to the Lower Triassic.

In drawing the outline of an Upper Triassic sea, the writer considered Chugwater above and below the Popo Agie beds as marine;

[1] F. R. von Huene, "Notes on the Age of the Continental Triassic Beds in North America with Remarks on Some Fossil Vertebrates," *Proc. U.S. Nat. Mus.*, Vol. LXIX, pp. 1–10.

Timothy and Ankareh in Idaho, Utah, Wyoming, and Colorado as mainly marine; the upper part of the Dolores as marine; and the widespread limestones and associated sandstones in the upper part of the Chinle as marine. All paleogeographic maps are imperfect, and the writer's more so than most, as it is based on suppositions of origin and age of formations that are in controversy.

SUMMARY OF DR. REESIDE'S DISCUSSION AND THE WRITER'S REPLY

1. Reeside agrees with Branson's main thesis that "large thicknesses of the red beds of the Rocky Mountain region present characteristics explainable only by the assumption of deposition in a very large body of water" (p. 48).

2. Reeside considers that a considerable part of some of the formations is eolian in origin, while Branson points out characteristics that seem to exclude most of the formations from this category.

3. Reeside does not agree with Branson that the vertebrates are at present of little use in making correlations, while Branson reiterates his opinion based on extensive studies of the largest collections that have been made.

4. Reeside correlates rather elaborately, but not dogmatically; and Branson points out weaknesses in the grounds for correlations that hold for almost all formations.

5. Reeside excludes Middle Triassic almost *in toto* from the red beds, and Branson points out the lack of evidences for this and the misinterpretation of the Popo Agie associations and conditions.

6. Reeside completely rejects Branson's map of Upper Triassic seas, but Branson points out that such rejection is based entirely on arbitrary correlations and assumptions of origin.

7. Reeside seems to consider Branson's correlation table as dogmatic. If he had read carefully Branson's paper, he would have found that the correlations are made in groups of formations and that Branson did not consider any correlation as secure.

OLD BEACH MARKINGS IN THE WESTERN WICHITA MOUNTAINS

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ABSTRACT

Some groovings or flutings are described that occur widely distributed in the granite area in the western end of the Wichita Mountains. Various possible ways in which the grooves might have been formed are discussed, and the conclusion is reached that they were probably formed at the edge of a salt lake or arm of the sea by the combined action of the water and climate.

The horizontally grooved granites in the west end of the Wichita Mountains have been observed by a number of geologists; but so far as the writer knows, they have been described only by C. H. Taylor[1] and by Dr. Samuel Weidman.[2] Taylor thinks they were caused by water action along old beach lines; while Weidman ascribes their origin to the work of glacial ice.

The markings are found at various places in the granite areas west of a line drawn north and south through Cooperton, Oklahoma. They have not been observed to the east of the line, or to the west of it in the gabbro mass on which the towns of Cold Springs and Roosevelt are situated.

The grooves are nearly always approximately horizontal, are of various widths from about an inch to 4 or 5 feet, and have a depth from about one-fifth to one-half of their width. They sometimes occur singly, but often cover a surface of considerable size. The largest surface so far observed is in the SW. $\frac{1}{4}$ of Sec. 33, T. 5 N., R. 20 W., and is about 375 feet long and 90 feet high. It is hard to say just what the vertical distribution of the markings may have been originally, as the lower part of the belt is now in the process of being uncovered by erosion of the red beds surrounding the granite masses and as the upper part is in places being destroyed by weathering.

Five possible ways have been suggested by which the markings

[1] C. H. Taylor, "Granites of Oklahoma," *Okla. Geol. Survey*, Bull. 20 (1915).

[2] Samuel Weidman, *Jour. of Geol.*, Vol. XXXI (1923), p. 466.

may have been formed: (1) by ordinary weathering, (2) by wind action, (3) by underground-water action, (4) by work of glacial ice, and (5) by work of water along a shore. Of these methods the first three would probably be almost at once rejected by any geologist observing the markings in the field, but were suggested to the writer as worthy of consideration by geologists who had not been in the area, and for that reason are discussed here.

FIG. 1.—Sec. 27, 5 N. 20 W. Showing how groovings, some only 1 inch across, go back into recession.

1. *Ordinary weathering.*—It is true that the granites of the Wichitas give rounded forms in many places as the result of weathering. However, the horizontal regularity and the vertical variation in size of these markings is unfavorable to the weathering theory. Also the variation in exposure seems to make no difference in the regularity and depth of the grooving, as would be the case in weathering.

2. *Wind action.*—If caused by wind action, the regular horizontal groovings could be formed in the absence of stratification only at the surface of the ground. In many cases, the grooves are too small and regular to have been formed in this way. Also we would expect wind work to be more effective on the side of the mountains toward the prevailing winds, and on exposed surfaces, than in recesses of the

rock; but the grooves are found equally well developed on all sides of the mountains, and as well developed in deep recesses as on exposed surfaces.

FIG. 2.—N.E. ¼ Sec. 7, 5 N. 18 W. Showing how grooves run back into recessions.

3. *Underground-water action.*—It has been suggested that layers of porous water-bearing sandstone, separated by impervious shale layers, lying up against the granite mountain, might cause the grooving by a sort of underground weathering. However, in those places where the groovings are being uncovered by erosion, the surrounding red beds do not have this structure.

4. *Work of glacial ice.*—This has been suggested by Weidman[1] although he states that he has not seen all of the exposures of grooved granites. Some of the surfaces do have a strong resemblance to ice work, but closer examination shows many features different from ice action and some that are impossible for ice work. Glacial ice will groove and striate a rock face and will enter curved recesses if the radius of curvature is not too short, but it will not turn at a right angle and enter a triangular recess and carry the grooving to the apex of the recess and come out again. This is what has occurred in

[1] Samuel Weidman, *op. cit.*

dozens of places on these grooved faces. For example, in the NE. ¼ of Sec. 7, T. 5 N., R. 18 W., there is a place where a groove about 10 inches wide and 4 inches deep passes along the face and turns at a sharp angle into a triangular recess about 16 inches wide and 3 feet deep and, without change in shape or size, reaches to the apex of the triangle and comes out again on the other side and continues along the face. In another place a somewhat larger groove enters a recess about 2 feet wide in front and 8 feet deep and comes out again. On the south side of Soldier Mountain at about 150 feet from the bottom is what appears to be an old sea cave. It is wedge shaped and is about 6 feet wide in front and 30 feet deep. Here, large horizontal grooves continue clear back to the apex.

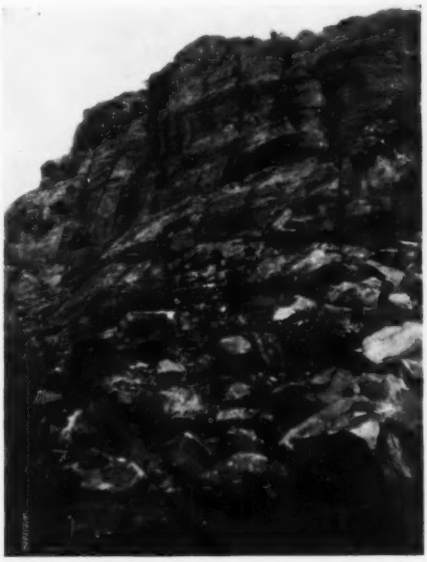

FIG. 3.—Sec. 31, T. 5 N. R. 20 W. Note how grooves penetrate recesses. This face is about 75 feet high and 300 feet long.

On Sec. 7, T. 5 N., R. 18 W., are recently uncovered inliers of rock 3 or 4 feet high and perhaps 20 feet in diameter. These have large grooves running around them horizontally and equally deep on all sides, but no grooves running over the top. These are evidently not *roches moutonnées*, because on a *roche moutonnée* of these dimensions, the glacial ice, instead of grooving horizontally around the mass, would go over the top and groove and striate in a direction parallel to that of the ice movement.

In places in the general belt where the groovings occur, the rock surface is polished. This polishing occurs sometimes in the grooves but is just as frequently on surfaces where no grooving is present.

The polished surfaces have almost a glassy smoothness but are slightly irregular; and the depressions, which will perhaps average $\frac{1}{8}$ inch deep and appear to be due to slight irregularities in the resistance of the rock, are as well polished as any other part of the surface. There are no striations on these polished surfaces, as there would be if they were due to ice action; but the irregularities of the surface are as pronounced in one direction as another. As polished surfaces similar to these can be found at various places in the adjoining mountains where the present streams are running over the granite surface, it seems entirely possible that these surfaces might also have acquired their polish as the result of water action.

FIG. 4.—NE. ¼ Sec. 7, 5 N. 18 W. Showing undercutting. Beyond the hammer as boulder has dropped down.

5. *Work of water.*—If we eliminate ice work, this leaves the action of water along a shore line as the only possible agent. Water could penetrate the triangular recesses in the rocks as described above and affect them equally with the more exposed surfaces. It would seem also that water is the only agent that could groove a boulder or stock horizontally around and equally on all sides.

The grooves were formed before the present red beds were laid down, because they are now being uncovered by erosion. They could

not have been formed very long before deposition of the red beds, else the markings would have been weathered out before being covered, as they are now being weathered rapidly away after being uncovered. It therefore seems probable that if they were formed at the edge of a lake, or sea, it was the same body of water in which the red beds were deposited. The groovings are not very large in many cases, and it would seem that the body of water in which they were formed was often without much wave action and so was probably not very large and had little or no tide. The work of groove-making was probably both chemical and physical; that is, the wetting and drying along the edge of the water hastened the weathering of the granite by causing slight changes in temperature and the crystallization of the salts in the absorbed sea water. It is also probable that this granite has more soluble constituents than the average granite. That these granites are more soluble than the ordinary granite is indicated by an analysis published by Taylor[1] of seven granites in which the Lugert and the Reformatory granite which contain these grooves are shown to be low in alumina and lime and high in soda and potash. The rocks of this region are at the present time more readily acted on by water in this way than is usual with igneous rocks. In Sec. 36, T. 6 N., R. 21 W., there is a very large unbroken exposure of granite; and where the water runs down the face after a rain, regular channels have been weathered out. One of these is about 18 inches wide and 5 inches deep. Similar channels have also been observed on Soldier Mountain. This being the case, it would seem that an agency that would alternately wet and dry the rock along a horizontal line would cause a horizontal groove to form in a relatively short time. It is also probable that the effect of salt water would be more rapid than that of fresh water. It would seem then that these grooves might have been formed in a salt lake, or small arm of the sea, at a time when the water was gradually advancing and the present red beds of the area were being deposited.

Regardless of what agent may have produced the groovings, it is of interest to consider why they occur only in the granites of the western end of the mountains and not in the central gabbro mass or in the granites of the eastern part. Evidently either the agent which

[1] C. H. Taylor, *op. cit.*

caused the groovings operated only in the western part or, if the grooves were once present in the east, they have since been obliterated. This condition could easily occur if water were the agent, but we would hardly expect that in such a relatively small area as the Wichita Mountains there would be such a heavy glaciation in the western part and no indication of ice action in the eastern part. It is the writer's opinion, after five months of rather intensive study of the Wichita Mountains, that the absence of the markings in the east can be explained by the difference in the rocks of the eastern and western parts. The gabbro weathers very much more rapidly than the granite, and any markings in it quickly disappear. The granites of the eastern and western parts do not appear on superficial examination to be very different, but the difference in weathering is considerable. In the east, the granites weather down rather quickly to fine red soil; and almost no small angular material, or granite "wash," is found around their bases. The mountains of the western end are surrounded by great deposits of granite "wash," which is being used for road materials in various parts of the state. Also the granite surfaces of the eastern end are not channeled by rain water to any such extent as in the western end; and so, if the old sea was present in the east, its effect on the rocks would not have been so great as in the western end. The granites of the eastern end are also, in general, more closely jointed and not so massive as those of the west, and so are apt to break down and form slopes more quickly; and it might be that any grooves that were formed in the eastern end, at the edge of the old sea, were largely obliterated by weathering before being covered by the red beds.

THE DUCHESNE METEORITE: AN UNDESCRIBED FIND FROM DUCHESNE COUNTY, UTAH

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The subject of this paper was made available to the writer for study through the kindness of Dr. Frederick J. Pack, and the department of geology in the University of Utah.

This meteorite originally weighted 50 pounds and is roughly lens-shaped, somewhat elongated, and flattened on one side. A furrow about 5 cm. wide and a third as deep runs the entire length of the convex side. A residue of troilite in its deeper portions suggests strongly that it has resulted from the fusion of a large cylindrical nodule of that substance. A deep hole at one end of about the same diameter has probably resulted from another nodule of troilite. The most striking external feature of the specimen is an exposure in the form of an escarpment from 1 to 2 cm. in height extending the full length of the meteorite (see Fig. 2, in which the octahedral plates show very distinctly on the uncut surface). Observed from the exterior, this exposure looks as if it had resulted from a faulting of the specimen; but a cross-section of the mass evidences no trace of dislocated lamellae. The exposure has therefore probably resulted from a disruption of a larger mass in the process of falling through the atmosphere.

The iron cuts with somewhat less resistance than some meteorites. We sawed through it in four hours with a hand saw, on a plane comprising about 6 square inches.

Polishing reveals faintly the Widmanstatten figures without the use of acid. Numerous small nodules of troilite are scattered over almost any cut surface.

Etching is accomplished quickly with a 10 per cent solution of HNO_3 producing a very clear and beautiful pattern of fine octahedral plates ranging in thickness from .15 mm. to .35 mm. when measured on a surface parallel to the octahedral face; and about one-third thicker when on a surface transverse to this face.

The lamellae are frequently massed together as shown in Figure 3, sometimes as many as fifteen without the intervention of anything but the very thin plates of taenite.

The regular straight kamacite bands are in some parts much crossed with broad irregularly swollen bands of the same material as is well shown in Figure 3. These bands are frequently bordered

FIG. 1

by an acid-resistant metallic substance of a bronzy luster which at first was mistaken for schreibersite; but which proved quite ductile when prodded with a needle. Its nature has not yet been determined.

The taenite plates are typically abundant, thin, and wavy. Plessite fields are large and distinct.

This meteorite resembles very closely the Hualapai (Arizona) iron recently described by Dr. Merrill. So close indeed is the resemblance that had it not been found several hundred miles distant, we should have considered it a part of the same fall. They differ,

however, in the content of troilite and schreibersite, Duchesne containing many nodules of the former and very little of the latter; while Hualapai so far as investigated shows abundant schreibersite in irregular masses, and, according to Merrill, no troilite.

The iron shall be known as Duchesne and is classed as a fine octahedrite of the variety Of.

FIG. 2

Chemical composition as determined by Mr. F. G. Hawley of Anaconda Copper Co. is as follows:

Fe	89.26
Ni	9.20
Co	0.41
Cu	0.08
Cr	trace
Mg	trace
P	0.21
S	0.01
SiO_2	0.15
C	0.07
O	0.44
Total	99.83

Supplementary notes.—My description of the Duchesne Meteorite was based upon the study of upward of 1500 grams of the mete-

orite, cut from one end of the mass; 500 grams of this was cut into very thin slices. What follows in this note should lend emphasis to

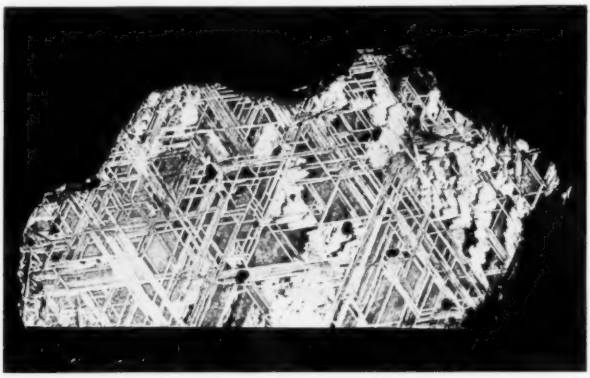

FIG. 3

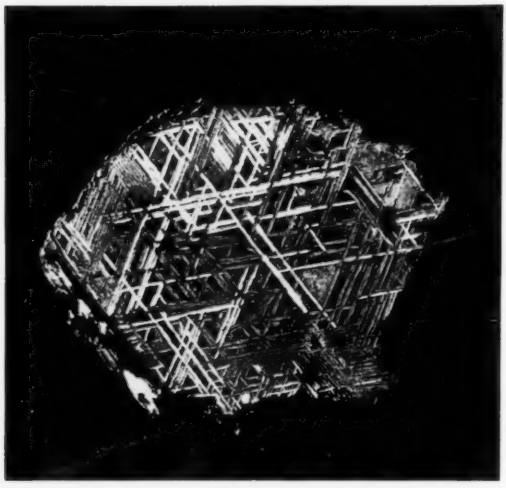

FIG. 4

the oft-repeated suggestion by Dr. Merrill that descriptions of meteorites are too often based upon the study of a few grams of a large

mass. Fifteen hundred grams would seem to be a rather generous amount for the purpose; but in at least one case it was not so.

In July, 1928, the writer arranged with the department of geology, University of Utah, for the cutting of additional material from the Duchesne iron, in order to further investigate a peculiar metallic substance which had been found in very small quantities during my previous work.

In the process of cutting this additional material we encountered large nodules of a non-metallic substance, which in appearance closely resembled troilite, and which was so considered, until a test was made with nitric acid, which failed to dissolve it. Various concentrations were tried, all with the same result. It was found to dissolve slowly in HCl and more readily in aqua regia. Though a small piece was left in 50 per cent nitric acid over night with no indication of dissolving, it dissolved readily when the acid was heated.

According to Merrill, Farrington, and others, troilite is readily attacked by nitric acid. In fact this character is one that distinguishes it from terrestrial pyrrhotite. In my own experience, I have found it very necessary to laquer nodules of troilite before etching iron meteorites in order to prevent staining of the metal. But in the case of Duchesne the large nodules occasioned no staining.

A sample was submitted to Mr. F. G. Hawley, of the Anaconda Copper Co., who rendered the following report of analysis:

	Per Cent
Iron	62.96
Nickel	.16
Cobalt	.02
Sulphur	36.25
Phosphorus	.02
Carbon	trace

Samples have been submitted to Dr. George P. Merrill and to Dr. Charles Pelache for their examination.

The nodules ranged in size from 1.5 cm. to 3.5 cm. in diameter; and a spindle-shaped one measured 5.5 cm. in length, from one point to its truncated end where it had been oxidized off at the surface of the meteorite.

A NEW METEORITE FROM BALLINGER TEXAS

H. H. NININGER
McPherson College

The small iron which forms the subject of this paper came into my possession by purchase from Mr. Hart, mineralogist, of Manitou, Colorado. The specimen has been sliced, half of the mass being in

FIG. 1

the U.S. National Museum at Washington, D.C. Nothing is known of the time of the fall of this meteorite.

Externally the specimen presents an appearance not unlike that of the typical octahedrite—an irregular mass, noticeably thicker at one end, its surface showing considerable oxidation and several small fissures. The total weight was 1,250 grams, or about $2\frac{3}{4}$ pounds.

Upon cutting the iron proved to be somewhat granular—the granules being of various shapes and sizes (see Fig. 1). Etching produced a very attractive face of variously oriented granules, which under slight magnification exhibited abundant and very distinct

intragranular Neuman lines. A few very thin plates of schreibersite are scattered over the various etched slices, and several irregular masses of triolite.

FIG. 2

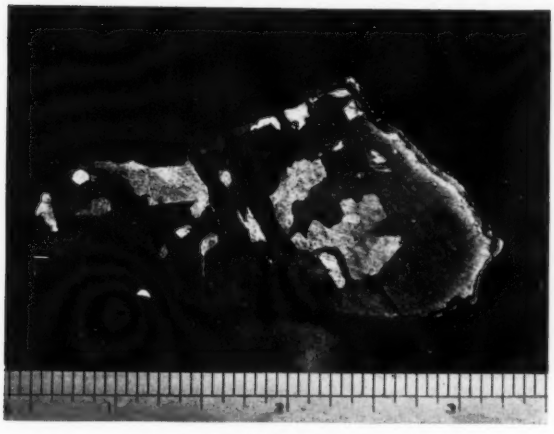

FIG. 3

A chemical analysis was made by Mr. F. G. Hawley, of the International Smelting Co., Miami, Arizona, as follows:

Fe	91.48
Ni	6.54
Co	.48
Cu	.07
Cr	trace
Mg	trace
P	.26
S	.01
SiO_2	.12
C	.09
O	1.03
Total	100.08

Combinations:

FeS	.03
Fe_2O_3	3.21
NiO	.30

Mr. Hawley also made a determination for platinum and secured a showing of .19 ounces per ton.

REVIEWS

Grundzüge der Geologie. Mit Unterstützung zahlreicher Mitarbeiter herausgegeben von PROF. DR. W. SALOMON. Band I, *Allgemeine Geologie*, Teil I: "Innere Dynamik"; Teil II: "Äussere Dynamik." Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung, Teil I, 1922; Teil II, 1925. Pp. 877. Band II, *Erdgeschichte*, Teil I: "Archaikum, Proterozoikum, Paläozoikum"; Teil II: "Mesozoikum und Neozoikum." Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung, Teil I, 1925; Teil II, 1926. Pp. 615.

The first volume bears the subtitle: "A textbook for (university) students, mining engineers, and engineers in general" (free translation). True to European tradition, the book betrays no special efforts of anyone to make it "simple," although there is a minimum of footnotes and references compared to other *Lehrbücher*. Throughout, the student is tacitly assumed to be a man with maturing critical faculties and with a sound background of basic scientific knowledge, and therefore both able and willing to make intelligent use of documentary detail offered.

In particular, however, this book is the very embodiment of the desire to present geological knowledge in the light of the newest advances and of work actively in progress. Since the rate of increase of geological knowledge has become such that no single mind can keep up with it, even a master in designing a textbook must sacrifice either artistic unity or scientific adequacy. Salomon decided to sacrifice the former. Thus this book has been made the work of a staff of men, each a recognized master in the field he covers.

The fourteen chapters of the first volume were written by eleven men: J. Koenigsberger, on the shape and physical properties of the earth (27 pages); W. Salomon, on the rock materials of the earth's crust (20 pages); A. Bergeat, on plutonism and volcanism (76 pages); W. Salomon, on orogenesis (48 pages); A. G. Högbom, on epeirogenic movements (29 pages); A. Sieberg, on earthquakes (63 pages); L. Milch, on metamorphism (61 pages); P. Krusch, on ore deposits (32 pages); K. Andrée, on the sea and its work (173 pages); W. Salomon, on the work of terrestrial waters (63 pages); H.Philipp, on the work of ice (56 pages) S. Passarge, on the work of wind (62 pages); K. Andrée, on the work of organisms (76 pages). A

chapter by S. von Bubnoff on the geological structure of Europe (50 pages) closes the book.

While the authors followed in general a common plan, each was made solely responsible for his part and was allowed the greatest freedom, not barring contradictory statements. We quote (in free translation) from the Preface:

> The beginner should derive a special advantage and stimulus from the discovery, through contradictory opinions of such eminent scholars, that a textbook of science is not a religious catechism, in which for each question there is but one correct answer. He will not be misled into thinking that the science he is dealing with is a completed edifice of dogmatic doctrine. He will realize at once that its contents are constantly undergoing changes; that many questions are far from being settled and are in urgent need of further study; that critical scrutiny is needful everywhere. He is led to form his own judgment instead of being made to swear "in verba magistri."

With almost complete liberty granted the authors, it is natural that the parts differ vastly in method of presentation, and even in proportionate length. The first chapter by Koenigsberger on the shape and physical properties of the earth contains a remarkable amount of information condensed into twenty-seven pages. It is the most concentrated summary of physical knowledge (as contrasted with geological speculation) concerning the earth as a whole that is known to the writer. It is most stimulating, but only to him who approaches it with an adequate background of physical knowledge and with a considerable maturity of mind. Many sentences are compressed into telegram style. Abundant reference is made to specific pieces of work, but they are quoted only by the author's name and year of publication. It is difficult to imagine a chapter more unfit for assignment to a class of our university undergraduates.

In careful diction and in didactic wisdom the chapters written by Salomon offer a great contrast to the first. Salomon has striven scrupulously to eliminate subordinate detail and to group his material in print in the most effective manner. To the reviewer it seems that the suppression of detail has been carried too far.

Andrée, on the other hand, offers one hundred pages on the constructive work of the sea without one single subhead, the larger part of his chapter on the sea (173 pages). This, like the chapter on the work of organisms, contains much valuable detail that one misses in the corresponding pages of Twenhofel's "Treatise on Sedimentation."

With all these and other obvious external differences in scope and method, there exists a basic harmony in tone. All chapters are written

with a fine emphasis on concrete observation, on the tangible realities which are, after all, the heart of scientific work. Observation, measurement—concrete things occupy the center of thought. Speculation, hypothesis, theory, arise in the course of inductive reasoning. The absence of deduction charms or shocks the American reader, according to his age and constitution. This, coupled with the refreshing absence of the conventional, which grows inevitably from the far-reaching individuality of each chapter, gives these volumes a peculiar value. They constitute a most significant addition to the literature that summarizes geological knowledge.

That the *Grundzüge der Geologie* is not a "textbook" in the more specific American sense of the word is best shown by the last chapter. Here, on forty-eight pages, von Bubnoff has given an outline of the geological structure of Europe more specific than the summary in Neumayr's *Erdgeschichte* which for decades has stood alone in the literature available to the general student, at least outside of Europe. As a key to the geological map of Europe, this chapter is of special value to the foreign geologist. The tectonic sketch map of Central Europe, on the scale of about 1:2,500,000, which accompanies this chapter, is well designed, both in selection and quantity of detail shown. A second map shows only the broadest tectonic units of the whole of Europe (on the scale 1:25,000,000).

In the second volume of this important *Lehrbuch*, even more than in the first, the advantages of the co-operation of a number of specialists are found to outweigh the disadvantages. The description of the geological periods is the work of nine authors: J. J. Sederholm, Archaic (22 pages) and Proterozoic (15 pages); A. Born, Cambrian (37 pages), Ordovician (48 pages), Gotlandian (51 pages); R. Wedekind, Devonian (33 pages); H. Harassowitz, Carboniferous (48 pages) and Permian (34 pages); A. Wurm, Triassic (32 pages); E. Dacqué, Jurassic (44 pages); E. Stolley, Cretaceous (32 pages); F. X. Schaffer, Tertiary (38 pages); K. Keilhack, Quaternary (30 pages). The systematic discussion of the periods is preceded by a brief chapter (20 pages) by W. Salomon on the basic concepts of historical geology. It is followed by three special chapters: a survey of the evolution of animals in the course of geological history, by F. Broili (24 pages); the evolution of the plants, by H. Salfeld (4 pages); fossil anthropoids and men, by Th. Mollison (40 pages). A too brief table of the chief events of geological history, designed by L. Rüger, concludes the volume.

Sederholm's chapters on the pre-Cambrian are examples of cautious, critical writing. A wholesome sense of uncertainty concerning pre-Cambrian correlations pervades the chapters. It is probably responsible for the complete absence of correlation tables.

The chapters on the Paleozoic periods contain each a table of the chief physical events. These tables are necessarily incomplete and may even be misleading where they fail to indicate that events have been of local and not world-wide occurrence. Yet they are so valuable that one regrets their omissions from the post-Paleozoic chapters. In this book, at last, German authors have broken away from the traditional "Silurian" and have replaced it by "Ordovician" and "Gotlandian," with a separate chapter devoted to each. The "Karbonformation," on the other hand, is not only retained as a unit; but the lower Carboniferous is given too little space. (The American name for the latter is misspelled "Missippian" on page 259. This, like "Beekmanstown" and "Champlaining," requires correction).

With astonishment the foreign reader beholds two chapters in a German textbook entirely devoid of references to the literature (Tertiary, Quaternary). In the chapters on the Cretaceous and Tertiary, very little space is given to inorganic events, in contrast to such fine discussions as, for instance, those on the orogenic movements of the late Paleozoic. No space is given to speculations concerning the causes of glaciation. The climatic problems, in general, are given too little attention throughout the book.

In all chapters on the Mesozoic and Cenozoic, the record of the vertebrates is given insufficient emphasis, both in text and in illustrations. In the text this deficiency is partly overcome in Broili's chapter on the evolution of the animals.

Mollison's elaborate chapter on fossil anthropoids and men plays a rôle analogous to von Bubnoff's chapter at the end of the first volume. It gives a most concise and concrete summary of a borderland of historical geology, and thereby gives a unique touch to the volume it concludes.

The whole work deserves to be ranked with the most valuable of European texts. The reader accustomed to the ways of our colleges should beware, however, lest he judge it otherwise than in the light of the editor's words:

> A man who desires to do serious work in geology must command a sound knowledge of biology, for one phase of his study, and a good foundation in mathematics, physics, chemistry, mineralogy, geography, meteorology, for the other. He who fails to serve from the bottom up along these lines will remain a dilettante all his life.

W. H. B.

Elements of Optical Mineralogy. Part I. Principles and Methods. By ALEXANDER N. WINCHELL. New York: John Wiley & Sons, 1928. Pp. viii+238; figs. 260.

The third edition of this well-known and deservedly popular book shows an increase of 22 pages and 9 figures over the previous edition. The second edition contained 208 pages of text, and these are given here practically unchanged, the additional material being confined to the final 22 pages. This new chapter gives 6 pages to the Fedorow stage and the rotation method for the determination of the optical properties of crystals, 8 pages to the determination of refractive indices by the dispersion method as developed by Merwin, Tsuboi, and Emmons, and 6½ pages to directions for laboratory work relating to these two methods. The minor changes in the first 208 pages are simply the addition of an example on page 24, of several bibliographic references on page 28, of Clerici's solution on page 30, of hafnium to the table of chemical elements on page 34, a rearrangement of text and figures on page 54, an error corrected on page 55, a short description and an illustration of the Winkel microscope on page 60, a few words omitted on pages 65 and 72, a paragraph of 8 lines added to page 73, a new address on page 74, 3 new lines on page 76, and two examples added to the scale of refractive indices on page 77. On page 153 "three major axes" is changed to "three symmetry axes," but "wave-front" is still used for the ellipsoid of "ray-fronts," although one is an ovaloid and the other an ellipsoid. On page 155 there is a slight change in the wording of the first paragraph and a line is added to the next, and on page 156 the wording is slightly changed. Page 195 is entirely rewritten and a figure is added, and finally, on page 207, figure 251 is redrawn with slight changes.

In appearance, binding, and printing the book is like the preceding edition.

A. J.

Alluvial Prospecting. By C. RAEBURN and H. B. MILNER, with a Foreword by J. D. FALCONER. Pp. 478; 32 plates; 139 figs. London and New York: D. Van Nostrand & Co., 1927. $14.00.

This book is a comprehensive scientific treatise of all phases of alluvial prospecting. The authors have spared no efforts in outlining the sequence of events from the origin of the detrital materials, their transportation and subsequent deposition, finally to their discovery and identification.

In the course of reading, it is interesting to note the evolution from

the simple "rule-of-thumb" methods of the early type of prospecting, through adaptation to changing conditions, to those of a prospector well trained in geology who is able to apply all methods of the science in accomplishing his ends.

The first few chapters deal with formation and classification of alluvial deposits, the association of minerals from the weathering of various types, and a list of the common associations of the most valuable placer minerals.

Various prospecting methods are described in subsequent chapters which convey the general idea of their importance, a subject which could hardly be expected to be treated exhaustively in a book of this scope. Mineral tables for field determinations follow, and add greatly to the value of the book. These are supplemented in the closing chapters by laboratory methods and descriptions of the most important detrital minerals. The descriptions are very ably supported by photographs.

The only valid criticism that can be made is the almost prohibitive price of the book—$14.00—especially in view of the fact that the most valuable chapters of this book, with the exceptions of a few additions, can be purchased at a much more reasonable price, since they are included in Milner's *Sedimentary Petrography* and *Supplement to Sedimentary Petrography*.

W. A. W.

Experimentelle Mineralogie. By RUDOLF GROSS. Part VI of Division 10 ("Methoden der Geologie, etc.") of the *Handbuch der biologischen Arbeitsmethoden*. Berlin: Urban and Schwarzenberg, 1928. Pp. 659–750. Mk. 5.

This work describes the modes of attack used by the physical crystallographer on certain of his problems, including crystal structure. Space is not available for anything like a complete discussion of the methods used, as the division title would seem to imply. The number lacks Index and Table of Contents, which presumably are included in the larger units. It has doubtful value for the working crystallographer, but may help the scientist, specialist in another field, who desires some understanding of physical crystallography.

D. J. F.